GENERAL SCIENCE

PART III

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GENERAL SCIENCE

PART III

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GENERAL SCIENCE

PART III

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PREFACE

This is the third volume of a series of four designed to include the basic principles of physics, chemistry, and biology. The authors aim at broadening the pupil's outlook by dealing with these subjects not only from the scientific standpoint, but also in their application to everyday life. In this way they hope that the study of science will exert a humanising influence on the pupil. At the same time they claim that such a course can train the pupil in scientific habits of thought.

After performing the experiments, students should write a clear connected account, with sketches where necessary, answering the questions as they arise. Disconnected notes must be discouraged.

The authors are indebted to certain sources for some of the illustrations, for which due acknowledgment is made in the text. They would also like to thank Mr B. M. Neville, B.Sc., of William Ellis School, London, for kindly reading the MS. and proofs, and for making valuable suggestions.

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GENERAL SCIENCE

PART III

CHAPTER I

PROPERTIES OF MAGNETS

In many parts of the world a dark stone is found, in appearance somewhat like a piece of iron, which has the peculiar property that when freely suspended it always points approximately north and south. From this property it was called *lodestone*, or "leading stone," the word "lodestone" being derived from the Anglo-Saxon word *lode*, meaning *way*. The lodestone was known in very early times, and many legends arose about it. One of these relates that as a shepherd in Asia Minor was walking along carrying a crook shod with iron, the crook was drawn from his hand by the attraction of lodestone in the earth. Another legend relates that in later times Mahomet's coffin was supposed to be suspended in mid-air, without visible support, by means of a powerful lodestone. Both these legends are mere fairy stories, but they testify to the manner in which the mysterious power of the lodestone fired the imagination of men.

The Mariners' Compass

The fact that a suspended lodestone pointed north and south was known early in history, and it is certain that a floating magnet was used as a compass as early as the twelfth century A.D. It was not until the sixteenth century that a pivoted compass, mounted in gimbals, came into general use. Gimbals were first used to keep oil lamps upright, and their use enabled the compass card to remain level in the roughest sea. The compass card is marked with the cardinal points, the magnetised needle being fastened to the under side.

In fig. 1 gimbals A and B suspend the compass box. Gimbals C and D at right angles to A and B suspend the inner ring in the fixed outer ring.

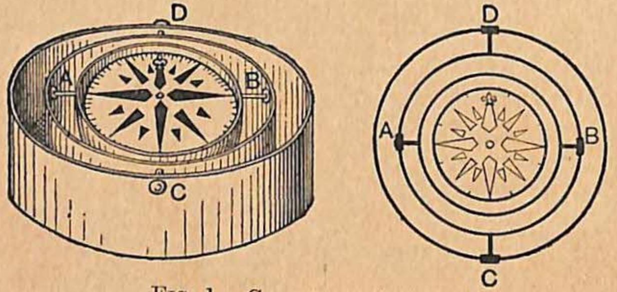


FIG. 1.—Compass and gimbals

The modern ship's compass is an elaborate instrument, consisting of several magnets mounted side by side. Special methods have been devised for counteracting the effect of the magnetism of the iron ship.

Experiments with Magnets

Small magnets of cobalt steel are very powerful, and a pair of them, cylindrical in section, are suitable for the following experiments :—

(1) Dip one magnet in iron filings. These cling mostly near the two ends, which are called the *poles*.

(2) Suspend each magnet in turn by a double loop of cotton and allow it to come to rest. Mark the ends which point towards the north. These are called north poles, or north-seeking poles.

(3) Hold the magnets in contact side by side on a bench, with north poles adjacent (fig. 2 (*a*)). Let them go. *What happens ? What do like poles do to each other ?*

(4) Place the magnets side by side, as in fig. 2 (*b*), with unlike poles adjacent. Let them go and note what happens. *What do unlike poles do to each other ?*

The experiments show clearly that

Like poles repel, and unlike poles attract each other.

How can we find out whether a bar of iron or steel is magnetised or not ?

Bring the ends and middle of an unmagnetised iron bar AB to each pole of a compass needle in turn. Repeat with a magnet and write down the results in columns as follows :—

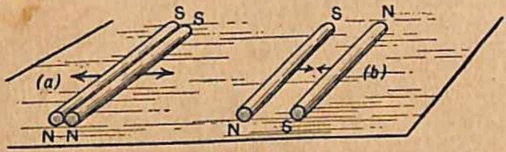


FIG. 2.

	Effect on compass	
	N.-seeking pole	S.-seeking pole
IRON BAR— End A . . . . End B . . . . Middle		
MAGNET— N.-seeking pole . . S.-seeking pole . . Middle . . .		

Apply one end of the unmagnetised bar (*a*) to the ends, (*b*) to the middle of the magnet, and note what happens. Repeat, applying one pole of the *magnet* to each end and the middle of the unmagnetised bar. Either pole of the magnet attracts the middle of the soft iron ; but the soft iron is not attracted midway between the poles of the magnet.

Use your observations to answer the following questions :—

(1) *How could you find, with the aid of a magnet, whether a bar of steel was magnetised or not?*

(2) *If you were given two bars of iron which look alike, one only being a magnet, how would you decide which was the magnet, using no apparatus except the two bars?*

Substances which are strongly attracted by a magnet are called **ferro-magnetic substances.** Examine as many substances as you can to discover which are ferro-magnetic. Be sure to include the metals nickel and cobalt. Arrange your results as follows, filling in the gaps :—

Substance	Effect of substance on magnet	Effect of substance on compass needle	Remarks: substance is
Iron .	Strongly attracted by both poles	Strongly attracted by both poles	Ferro-magnetic
Steel .			
Cobalt			
Nickel			
Glass	No effect	No effect	Not magnetic
Wood			
Etc. .			

The only ferro-magnetic substances known are iron and steel, nickel and cobalt. We usually call other substances non-magnetic. If a powerful electro-magnet is available, with detachable tapering pole pieces, you can try the effect of suspending between the pole pieces small thin pieces of various substances, hanging them by thin thread from a wooden

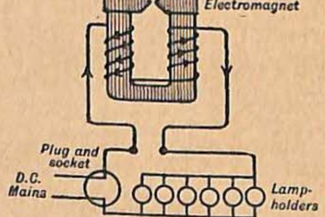


FIG. 3.

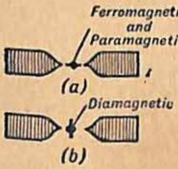


FIG. 4.

stand (fig. 3). When the substance is at rest switch on the current. You will find that **most substances are affected slightly.**

In 1845 Faraday showed in this way that some substances set as in fig. 4 (*a*) with axis between the poles; others set as in 4 (*b*) with axis at right angles to the poles. The former he called **para-magnetic,** the latter **dia-magnetic.** Bismuth is the best example of the latter.

Experiments on the Attraction of a Magnet through Various Substances

(A) **Solids**—Sprinkle a few iron filings on a sheet of glass. Bring one pole of a magnet below as shown in fig. 5. Repeat, using, instead of glass, wood, paper, sheet iron (a "tin" lid), and a nickel dish.

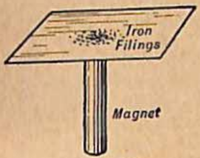


FIG. 5.

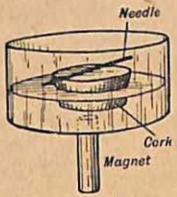


FIG. 6.

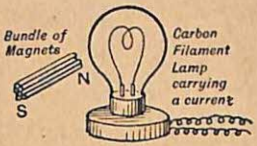


FIG. 7.

Which substances weaken the attraction, ferro-magnetic or non-magnetic?

How would you shield anything from magnetic attraction? If possible examine the electrical instruments on a switch-board. These are usually shielded by enclosing them in soft iron cases.

(B) **Liquids**—Float a needle on a cork in a bowl of water. Bring a magnet underneath (fig. 6). *Does the magnet attract through the water?*

(C) **Gases**—*Is a compass needle in a box affected by a magnet? Is magnetic attraction exerted through air?*

(D) **Vacuum**—Bring a bundle of cobalt steel magnets near a carbon-filament lamp (fig. 7). This consists of a spiral of carbon in a vacuum. *Is there any effect* (a) *when no current flows through the lamp,* (b) *when the lamp is lit up by a current?*

The carbon spiral, when lit up by a current, behaves like a magnet, and the fact that it is affected by the magnets shows that magnetism is exerted through a vacuum.

The last experiment suggests that **magnetic effects are produced by an electric current flowing in a wire.** The experiment with the electro-magnet described on p. 4 suggests the same thing. We shall examine the magnetic effect of a current in a later chapter.

QUESTIONS

1. Describe experiments to show how the attractive power of a magnet is modified (*a*) by sheets of non-magnetic material, (*b*) by sheets of magnetic material, (*c*) by a vacuum.
2. Describe briefly experiments which show that most materials are magnetic in some degree.
3. If you were given three similar bars, one a steel magnet, another of soft iron, and the third of non-magnetic material, what tests would you apply to find out which was which? Explain.

CHAPTER II

MAGNETIC LINES OF FORCE. MAGNETIC FIELDS. MAGNETIC INDUCTION. MAKING MAGNETS. EFFECT OF HEAT ON MAGNETISM

SIFT a thin layer of fine iron filings from a muslin bag on to a sheet of glass or cardboard held horizontally above a magnet. Tap the cardboard. The filings set in a pattern something like that shown in fig. 8. It is as though they set along invisible threads connecting the poles. The lines are called *lines of force* and the space in which the lines of force exist is called a *magnetic field.*

It is advisable to obtain permanent maps of several magnetic fields in order to study the lines of force. Such maps may be made by dusting the filings on sheets of waxed paper. After tapping the paper in order to allow the filings to set in position a Bunsen flame is passed quickly over it, melting the wax, which then sets with the filings in place. Another method is to sprinkle the filings on gaslight photographic paper, after which the paper is exposed and developed in the usual way. Suitable magnets are of cobalt steel, rectangular in section and about 2 in. long.

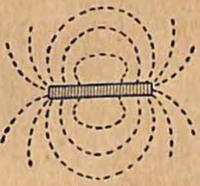
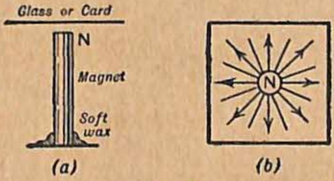


FIG. 8.



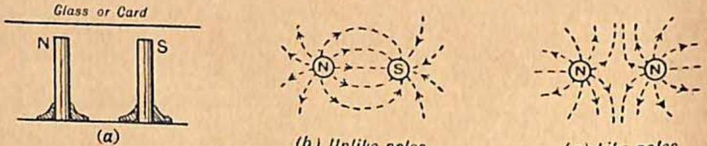
(a) (b)

FIG. 9.

Some Typical Magnetic Fields

(i) **Single Pole**—Set up a magnet as shown in fig. 9 (*a*) and obtain the map shown in fig. 9 (*b*).

(ii) **Two Poles**—Repeat the process with two poles as in fig. 10 (*a*), (*b*), and (*c*). The arrows show the direction in which a free north pole would tend to move.



(*a*) (*b*) *Unlike poles* (*c*) *Like poles*

FIG. 10.

Faraday's Conception of Magnetic Lines of Force

As the result of his study of magnetic fields by methods such as we have described, Faraday supposed magnetic lines of force to possess the following physical properties :—

(*a*) They tend to shorten in length ;

(*b*) They repel one another sideways.

These phenomena account for the attraction of unlike poles and for the repulsion of like poles.

To help in picturing the lines Faraday introduced the following conventions :—

(i) Their direction is that in which the north-seeking pole of a compass needle would point ;

(ii) Their number near any point is a measure of the strength of the field at that point. We find them concentrated most at the poles.

Obtain Maps with Iron Filings in the following cases (fig. 11) :—

(i) **Unlike poles adjacent,** as in fig. 11 (*a*) and (*b*).

(ii) **Like poles adjacent,** as in fig. 11 (*c*) and (*d*).

In each case mark with a X any neutral points. These are places where no magnetic force acts.

(iii) **Magnet with soft iron ring near,** as in fig. 11 (*e*). Only the lines near the ring are shown in the diagram.

Are there any definite lines of force inside the ring? What is the bearing of this experiment on the magnetic shielding discussed on p. 5?

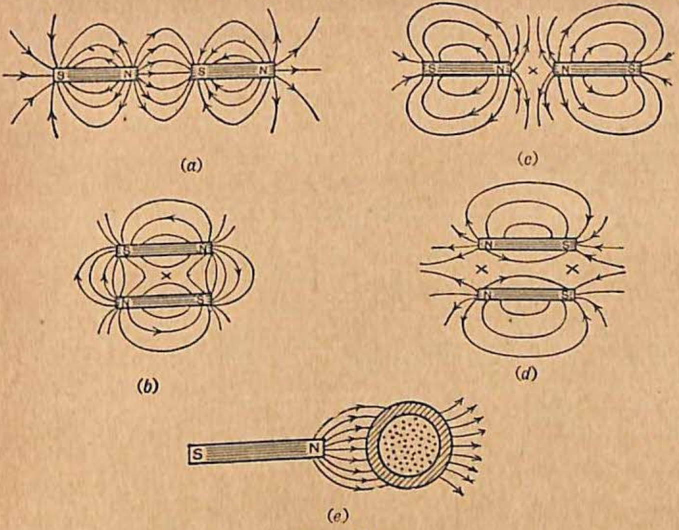


FIG. 11.

Plotting Magnetic Fields by Compass Needle

The compass tends to set with its axis tangential to a line of force. Use a very small pivoted compass in a box with glass faces. Make dots A and D (fig. 12) at the south and north ends respectively. Move the compass needle until the south end is over B, tap gently and make a dot C at the north end. By repeating this process the line of force may be mapped out. This method is much more sensitive than the filing method. For example, the earth's field is too weak to set iron filings but it affects the compass needle. It will be well for the class to split into groups to obtain maps showing the earth's magnetic field in the following cases :—

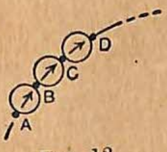
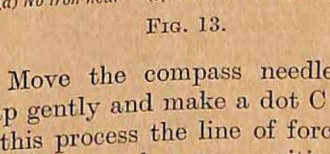


FIG. 12.



(*a*) *No iron near* (*b*) *Near an iron cylinder*

FIG. 13.

(*a*) On a bench with no iron near (fig. 13 (*a*)).

(*b*) Near an iron cylinder resting on the bench (fig. 13 (*b*)).

Draw the lines of force in your notebook. Note how the field is distorted near the iron, into which many lines of force are drawn.

Induced Magnetism

Place a poker or unmagnetised soft iron bar on the floor, pointing N. and S. Bring a compass needle near each end in turn to make sure it is not magnetised.

How do you make sure of this? Hammer it well and then bring a compass needle near each end in turn. Describe what happens. *What is the polarity of the end which pointed north?* We say the bar has become **magnetised** by **induction** in the earth's field.

Obtain a filing map for the case of a small soft iron bar near a permanent magnet (fig. 14). These are shown at one end of the magnet only. It is clear that lines of force enter one end of the bar and emerge from the other end. In fact, the soft iron bar has become a magnet by induction whilst under the influence of the permanent magnet. Remove the permanent magnet and use a compass needle to find out if any magnetism still remains in the soft iron. Then drop the soft iron on the floor and try again.

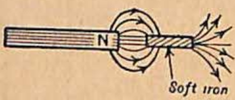


FIG. 14.

Other Experiments on Magnetic Induction

(i) Hang two soft iron nails from the N. pole of a magnet. Hold the ends together, and then let them go (fig. 15). Explain what happens.

(ii) Bring underneath the nails (*a*) another N. pole; (*b*) a S. pole. In each case observe and explain what happens.

(iii) Hang as many small soft iron nails as you can from a magnet (as shown in fig. 16). Hold the top one between your fingers and pull the magnet

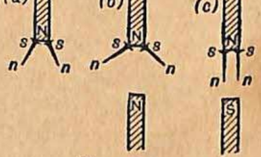


FIG. 15.

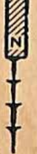
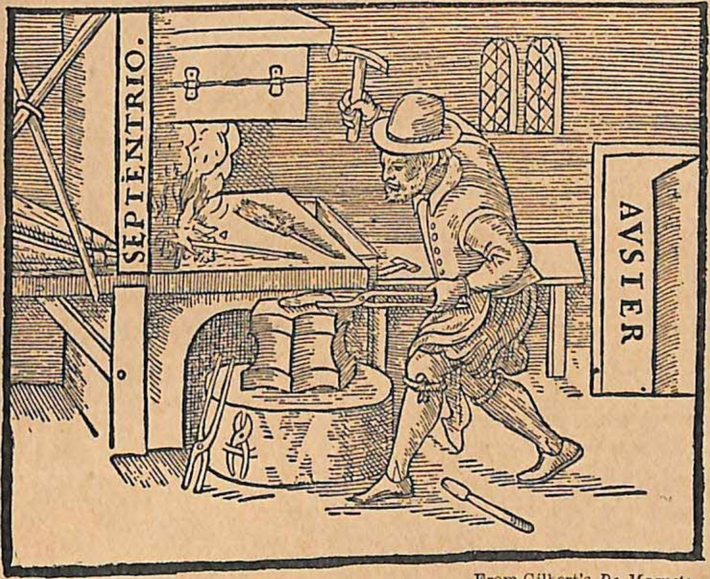


FIG. 16.

away. *What happens and why? Does soft iron retain its magnetism easily? What substance, soft iron or steel, would you use for a permanent magnet? Give reasons.*

Making Magnets

(*a*) **By Induction**—Some of the first permanent magnets were made by Gilbert (1540–1603) by allowing red-hot bars of steel to cool whilst pointing N. and S. and hammering them the while. The bars became magnetised by induction in the earth's field. The illustration shown (fig. 17), taken from Gilbert's great book *De Magnete*, shows a smith making a magnet in this way.



From Gilbert's *De Magnete*

FIG. 17.—A smith making a magnet by hammering a red-hot bar of iron which is pointing N. and S.

(*b*) **By Means of a Permanent Magnet**—Method of Single Touch. You have probably used this method in magnetising a knife blade. Stroke a thick piece of knitting needle one way only with the north pole of a permanent magnet (fig. 18).

After each stroke plunge the needle into iron filings and collect the heaps separately. *Is there any increase in the lifting power* (a) *after the first stroke,* (b) *after several strokes? Does this experiment suggest that the magnetism in the needle can be increased indefinitely by continued stroking with the pole of a magnet? What is the polarity of the end* (a) *at which you started,* (b) *at which you finished?*

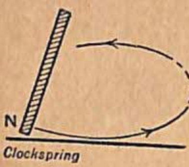


FIG. 18.—Magnetising by single touch

Repeat, using a south pole.

(c) **By Means of an Electric Current**—Obtain a cardboard tube about six inches long and an inch in diameter. Wrap 2–5 layers of No. 22 insulated copper wire on this, being careful to wrap the turns in the same sense throughout (fig. 19). Connect this to a tapping key and an accumulator as shown. Place compass needles near each end both inside and outside the coil, and press the tapping key. *What is the effect on the compass needles? Does the coil behave like a magnet when the key is depressed?* If so, mark the end which behaves like a north pole. *When the tapping key is released does the coil still behave like a magnet?*

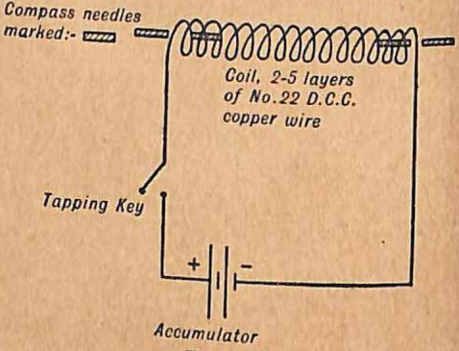

Compass needles marked:- ▭
Coil, 2-5 layers of No.22 D.C.C. copper wire
Tapping Key
+
-
Accumulator

FIG. 19.

Reverse the direction of the current by reversing the connection to the accumulator and then repeat the experiment. Write down what you notice.

The current flows out of the accumulator at the + terminal, which is usually coloured red. Now find out in which direction the current flows round the coil to produce a north pole at the end nearest to you. Fig. 20 shows end-on views of the coil. Insert arrows (in pencil) to show the directions of the current which produce the poles shown at the end nearest to you.

Now place in the coil a short unmagnetised knitting needle and press the key for a moment. Remove the needle and test if it is magnetised. Test also after it has been dropped on the floor. Repeat with a soft iron bar. Test for magnetism (*a*) *before* it is removed, after releasing the key, (*b*) *after* it is removed, and again after it has been dropped on the floor.

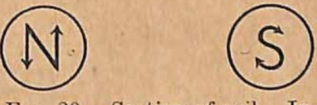


FIG. 20.—Section of coil. Insert arrows showing the direction of the current

What difference do you notice between soft iron and steel in regard to their power of retaining magnetism?

A Magnetising Coil for Use on the Mains

A coil such as we have described may be set up permanently for use in magnetising bars of steel. The permanent coil should consist of ten layers of insulated copper wire on a cardboard tube a foot long, and should be mounted as shown (fig. 21). It may conveniently be used on the mains if a suitable resistance is placed in series. The 5-amp. fuse wire is a safeguard against excessive current. The key should never be depressed for long periods of time.

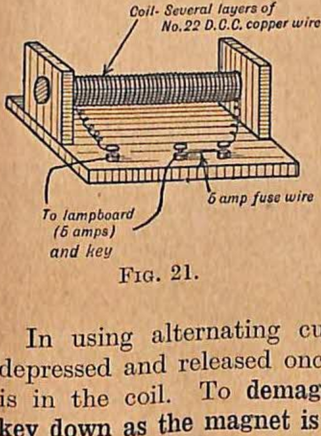
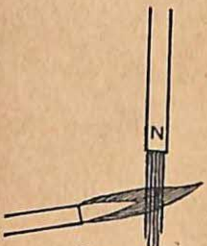

Coil- Several layers of No.22 D.C.C. copper wire
5 amp fuse wire
To lampboard (5 amps) and key

FIG. 21.

In using alternating current (A.C.) the key should be depressed and released once when the bar to be magnetised is in the coil. To **demagnetise a bar** completely **hold the key down as the magnet is pulled out and removed along the axis of the coil** through which **alternating** current is passing. This removal into a weaker **alternating** magnetic field eventually removes all the magnetism. **This cannot be done using direct current (D.C.).**

The Effect of Heat on Magnetism

Support a magnet in a stand and hang a small bundle of iron wire from the lower pole (fig. 22). Heat the wire with a Bunsen flame and watch what happens. Heat the magnet as little as you can. Raise the wire to bright red-heat. If it drops off apply another magnet, and note if the wire becomes magnetic again when cool. Repeat the experiments and make careful notes. If a strip of nickel is available the experiments should be repeated with it.



Bundle of iron wire heated by flame

FIG. 22.

The experiments show that **when magnetic materials are heated above certain temperatures they become non-magnetic, but regain this property when cooled.**

For steel this "critical" temperature varies from about 870° C. upwards according to the composition of the steel; for nickel it is as low as 320° C.; and for cobalt 1120° C. At about these temperatures some change takes place in the arrangement of the molecules of the material. Evidence for such a change is also provided by other phenomena which are found to occur at these temperatures.

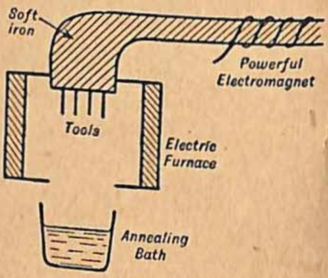


FIG. 23.

An **interesting practical application** is in the hardening of very hard steel boring tools. These are suspended in an electric furnace from a soft iron bar, which is magnetised by passing a current round a coil (see fig. 23). The furnace is heated, and when the tools get to the critical temperature they lose their magnetism and fall off into a cool oil bath below the furnace.

QUESTIONS

1. Show in sketches the magnetic lines of force (*a*) between like poles, (*b*) between unlike poles. Insert arrows to show their direction.
2. Show by a sketch how the earth's magnetic lines of force are modified in the neighbourhood of magnetic material.

3. How do you explain the attraction of a magnet for an iron nail?

4. What is meant by magnetic induction? Illustrate your answer from experiments you have seen or performed.

5. Explain how you would magnetise a piece of steel by means of the earth's magnetic field.

6. Describe carefully how you would magnetise a piece of steel using direct electric current. Indicate the direction of the current in a diagram, and mark clearly the polarity of each end of the magnet.

7. Given an accumulator and some covered copper wire, how would you magnetise a steel knitting needle so that it had a north pole at each end? Illustrate by a diagram.

8. How do soft iron and steel differ in their magnetic properties? Describe experiments to illustrate.

9. What is the effect of heat on the magnetism of iron? Describe an experiment to illustrate your answer.

CHAPTER III

THE MAGNETIC EFFECT OF AN ELECTRIC CURRENT AND ITS APPLICATIONS

An Experiment on the Magnetisation of Soft Iron and Steel. Making an Electro-magnet. Electro-magnets in Daily Life. The Electric Bell. Simple Galvanometers

Experiment on the Magnetisation of Soft Iron and Steel

You have learnt that a coil of wire behaves like a magnet when an electric current passes through it. Let us try the effect of gradually increasing the number of turns of a coil on the magnetism of a piece of iron or steel enclosed in the coil. Half the class should use iron and the other half steel. Bars 6 in. long × $\frac{1}{4}$ in. diameter are suitable for the experiment.

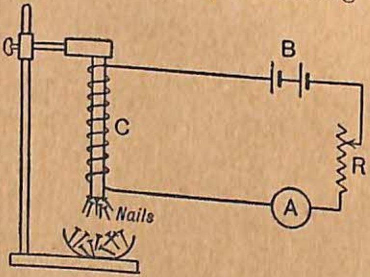


FIG. 24.

Fit up an electric circuit consisting of an accumulator, a rheostat, an ammeter, and several yards of No. 22 or No. 24 cotton-covered copper wire (fig. 24). The rheostat is a resistance which is used to adjust the current passing through the copper wire. Wrap fifty turns of wire round the bar and allow about an ampere to flow. Dip one end into some tacks and count the number picked up. Dip the end into the tacks again and count the number of tacks. Wrap another fifty turns round the iron and repeat. Continue to do this until you have wrapped about 400 turns of wire on the iron, but **always coil the wire in the same sense so that the same end of the coil is always a north pole.** The rheostat must not be disturbed, so that the current is the same throughout the experiment. When you have wrapped 400 turns lift the bar with tacks attached and then turn off the current. Note what happens to the tacks.

RESULTS

Current constant throughout experiment.
Material—soft iron.

No. of turns	No. of tacks picked up		Total
	(*a*)	(*b*)	
0	0	0	0
10	5	4	9
20	10	9	19
—			
—			
—			
200			

Plot the results on a graph (fig. 25).

It is clear that increasing the number of turns in the coil increases the magnetic effect of the current. The strength of the magnetic field of the coil depends on the product of the amperes and the turns — *i.e.* on the **ampere-turns**.

The graph shows three distinct parts, A, B, and C. Part A shows that the magnetism of the iron increases slowly as the number of turns is increased; part B shows a more rapid increase, but part C shows that eventually the amount of magnetism induced in the iron or steel reaches a maximum. The iron or steel is then said to be **saturated** with magnetism. From a study of the graphs and ex-

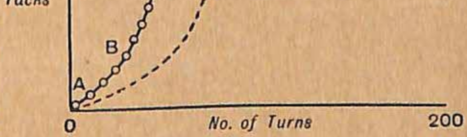


FIG. 25.

periments you should be able to answer the following questions:—

(i) *Which material, soft iron or steel, was the easier to magnetise?*

(ii) *Which is the stronger magnet when saturated?*

(iii) *When the current was switched off, which material retained the more magnetism?*

(iv) *Which of these materials, soft iron or steel, would be used for (a) an electro-magnet; (b) a permanent magnet? Give reasons.*

To sum up:—

Soft iron is more easily magnetised than steel and is also a more powerful magnet when saturated. Soft iron is more easily demagnetised than steel and is much less retentive of magnetism.

If D.C. mains are available the foregoing experiment is conveniently performed using a lamp-bank with one carbon-filament lamp inserted in a lampholder. A form of lamp-bank which the authors have found very useful is wired as shown in fig. 26. The materials cost a few shillings only, and a boy can make the lamp-bank in about an hour.

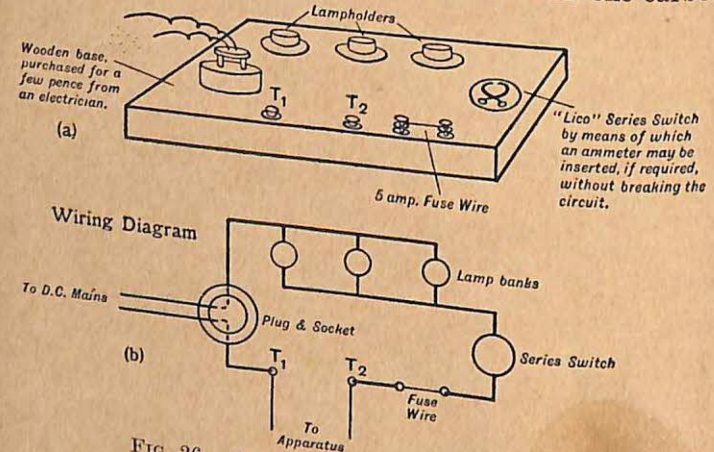

Lampholders
Wooden base, purchased for a few pence from an electrician.
(a)
T_1
T_2
"Lico" Series Switch by means of which an ammeter may be inserted, if required, without breaking the circuit.
5 amp. Fuse Wire
Wiring Diagram
Lamp banks
To D.C. Mains
Plug & Socket
(b)
T_1
T_2
Series Switch
Fuse Wire
To Apparatus

FIG. 26.—A lamp-bank for use on the mains

To make an Electro-magnet

Obtain a bar of soft iron about 8 in. long and ¼ in. in diameter. Heat it in the middle until red-hot and bend it into the form of a horseshoe (fig. 27). Fix it in a vice, and file the ends together until they are flat and in the same plane. A flat piece of iron should be prepared to act as an armature. Wrap several layers of No. 26 covered copper wire round the core, *always wrapping in the same sense. Why is this important?* Attach the ends of the wires to a tapping key and a 2-volt battery. (A torch battery will do.) Press the key and then find out the polarity of the ends of the core. Attach the armature to the core, and add weights until the armature falls off. Thus you will find the weight which may be supported. Release the key whilst the magnet is supporting the weights. *What happens and why?* Arrange for the electro-magnet to support the armature without the weights and then release the key. *Does the armature fall off at once?* Usually it sticks until disturbed, showing that some magnetism remains in the core. Pull the armature gently away, and then try to replace it without allowing current to flow. The armature cannot be replaced, showing that the core is now demagnetised. The electro-magnet you have made is the same type as the first one which was invented by an Englishman, William Sturgeon, in 1825.

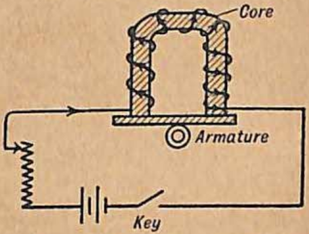


FIG. 27.

Electro-magnets in Daily Life

Electro-magnets are extensively used in industry, and their design is of very great importance. The simplest type is that which you have just made, and consists of a coil of insulated copper wire wrapped on a horseshoe-shaped piece of soft iron. This type is used in electric bells. It is important to wrap the wire throughout in the same sense, so that when the current is switched on the ends are of opposite polarity (see fig. 20). For lifting heavy weights, the type shown in fig. 28 is used. If a good lathe is available, a small electro-magnet of this type may be made by drilling a channel in a cylinder of soft iron of dimensions 3 in. × 1 in. and filling the space by wrapping No. 26 insulated wire on a cardboard former and inserting this in the channel. Molten wax should be run in afterwards and made flush with the surface. Such an electro-magnet will lift about 100 lb. with current from a 4-volt accumulator or dry cell. A suitable armature is a flat iron, from the handle of which the weight may be suspended.

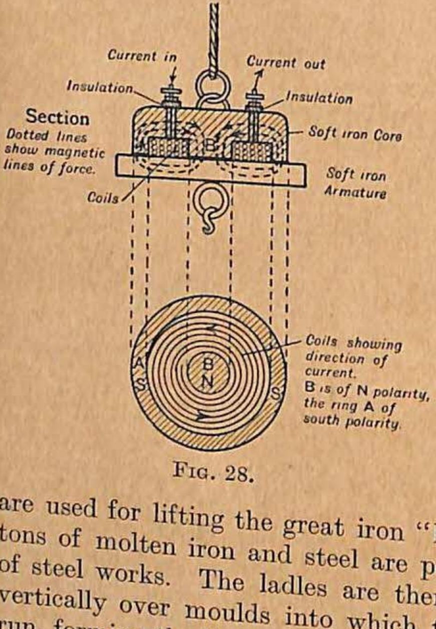

Current in
Current out
Insulation
Insulation
Section
Dotted lines show magnetic lines of force.
Soft iron Core
Soft iron Armature
Coils
B
A
S
B
N
S
Coils showing direction of current.
B is of N polarity, the ring A of south polarity.

Fig. 28.

Large electro-magnets of this type are in extensive use for lifting tons of material. Without the armature they are used for lifting scrap iron. Electro-magnets are used for lifting the great iron "ladles" into which many tons of molten iron and steel are poured from the furnaces of steel works. The ladles are then moved until they are vertically over moulds into which the molten iron is then run, forming the "pig iron" of commerce.

The Electric Bell

Examine an electric bell (fig. 29). Note the electro-magnet and the armature. *Of what materials is the armature and the core of the electro-magnet?* Note also spring S and the contact maker C. Trace out the connections from terminal T_1 to terminal T_2. Press the armature towards the electro-magnet. This should cause the striker to hit the gong, and should also separate the contact at C from the screw. If it does not, adjust the screw C until this happens. Connect a 4-volt battery and a tapping key to the terminals T_1 and T_2.

Press the key for a few seconds. *What happens to the core of the electro-magnet? What is the effect on the armature? What then happens to the contact C? What is the effect on the current?*

These questions should enable you to understand how the bell works. Write a full description in your notebook, illustrating it by a careful diagram.

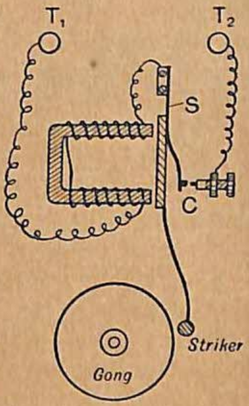


FIG. 29.—The electric bell

Further Experiments on the Magnetic Effect of an Electric Current

(1) Arrange a piece of straight insulated copper wire, AB, in a circuit as shown in fig. 30, or across the terminals of the lamp-bank described on p. 18 (fig. 26). Arrange for the wire to lie above and parallel to the axis of a compass needle. Start the current by pressing the key in the case of the accumulator circuit, or by inserting a lamp in the lampholder. The current is flowing from A to B. Note the direction in which the north pole of the needle is deflected. Repeat with

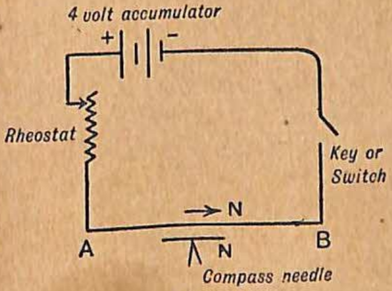


FIG. 30.

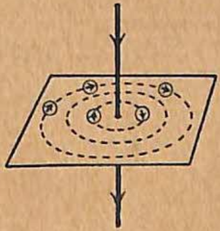


FIG. 31.

the needle (*a*) above the wire, (*b*) on its edge at each side of the wire. In each case record what happens, showing on a diagram the direction in which the north pole moves.

(2) Arrange for the wire AB to pass through a hole in a piece of cardboard which is supported in a horizontal plane by means of a wooden stand (fig. 31). Plot the magnetic lines

of force round the wire by means of a compass needle, using the method described on p. 9 (fig. 12). These lines are circular. Verify that their direction is given by **Maxwell's corkscrew rule**, which is stated as follows: **Imagine a right-handed corkscrew being screwed along the wire so that the point moves in the direction of the current. The direction of rotation of the handle gives that of the lines of force round the wire.**

The effect on a magnet of a current in a straight wire was discovered by Oersted, a Dane, in 1819, and the discovery formed the starting-point of many applications of electricity to the service of mankind. You have already studied the magnetic effect of a current in a coil, and should verify that Maxwell's corkscrew rule may be used to find the directions of the lines of force in this case also. You can now understand why coiling a current-carrying wire increases the magnetic effect of the current. Every turn added increases the magnetic lines of force and increases the magnetic field strength by the same extent. Thus a very small current flowing through a coil of thousands of turns may produce a very strong magnetic field.

Further Applications of the Magnetic Effect of a Current

Simple Galvanometers—Galvanometers are instruments for detecting and measuring electric currents. The first and simplest, made in 1820 by a German professor named Schweigger, was simply a rectangular coil of wire at the centre of which a magnetic needle was mounted (fig. 32).

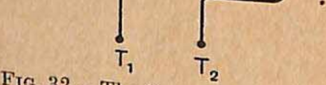


Fig. 32.—The first galvanometer

The coil was turned until its plane was along the axis of the needle. When a current was passed through the coil the needle was deflected, the deflection depending on the current. (The angle of deflection is not *proportional* to the current, but that does not concern us here.) This type of galvanometer is still in extensive use in the electric telegraph.

QUESTIONS

1. Describe an experiment showing the behaviour of iron and steel when gradually magnetised.
2. Sketch the lay-out of a modern electro-magnet, and briefly state the importance of each part.
3. Draw a diagram showing an electric bell, and explain how the bell works.
4. Describe a simple type of galvanometer. Explain how you would make one of these suitable for (*a*) heavy currents, (*b*) small currents.

CHAPTER IV

THE ELECTRIC MOTOR
THE MOVING COIL GALVANOMETER

Electric trains and trams, electric hoists and electric cranes, electric vacuum cleaners are all worked by some form of electric motor. Nowadays as alternating current is gradually replacing direct current, alternating current motors are coming into general use, and the principles on which they work are harder to understand than the principle of the direct current motor, which we shall now discuss.

Demonstration Experiment illustrating the Principle of the D.C. Motor

Straighten a long piece of No. 24 or 22 bare copper wire by gripping one end in a vice and pulling at the other end. Cut off about 8–10 inches, and loop the end over another wire B (fig. 33), so that it can swing freely. It is advisable to rub the two wires with mercury where they touch, so as to ensure good contact. Allow the lower end of the wire to dip into some mercury in a small porcelain boat. Support the opposite poles of two magnets arranged as shown, so that the hanging wire is between them. Complete the electric circuit with a switch, rheostat, and a 4- or 6-volt battery. Close the switch and adjust the rheostat until the wire moves. If the current is strong enough, the wire may be forced right out of the mercury, breaking the circuit, and when it falls back the same procedure is repeated. Reverse the magnets, and note which way the wire is then deflected.

The explanation of the behaviour of the wire should be understood by considering the magnetic field about the wire. Fig. 34 (*a*) shows the field between the poles when no current is flowing in the wire; (*b*) shows the field due to the current alone, when this is flowing *down* the wire; (*c*) shows the lines of force when (*a*) and (*b*) are combined. Evidently the field is strengthened on one side of the wire and weakened on the other. The magnetic lines try to straighten out, and in doing so they drive the wire forward. This is what happens in an electric motor. The magnetic lines of force try to shorten, and in doing so they cause a current-carrying conductor to move.

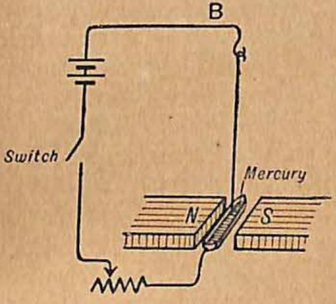


FIG. 33.

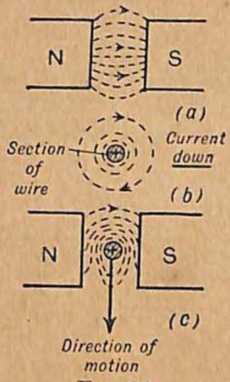


FIG. 34.

Now suppose that a coil of wire is wrapped round a cylinder which is mounted on an axis so that it can rotate between a north and south pole, as shown in section in fig. 35. Suppose that a current is led into the coil and that it flows down at A and up at B. The lines of force due to the magnetic fields of the current and magnet will be as shown, and there will be a tendency for the cylinder to rotate in an anti-clockwise direction. When AB gets into position CD there will be no further tendency for the coil to rotate, but when B gets to the position A the direction of rotation will be reversed *unless the current in the coil is reversed.* This reversal is necessary if the cylinder and coil are to continue rotating in the same direction. To reverse the current a **commutator** is necessary. This consists of a split copper cylinder fitted on to the shaft,

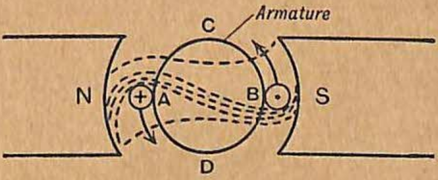


FIG. 35.

the two halves being insulated from the shaft and pressing against two fixed carbon brushes, which lead the current in and out. These brushes are so placed that the current always flows *down* on one side of the armature and *up* on the other whatever the position of the coils. Fig. 36 shows the coil without the cylinder on which it is wrapped. The brushes are so arranged that when the coil is in a plane at right angles to the lines of force the current in it is reversed, and so the coil continues to rotate in the same direction. In a large machine several coils are wrapped on an armature made of soft iron stampings—thin discs of soft iron mounted on the shaft and insulated from each other. The ends of each coil are connected to segments of the commutator. Instead of permanent magnets, electro-magnets are used. The casting of the electro-magnets, called the Yoke, is of cast iron, and the coils, commutator, and brushes of two types of a D.C. machine are represented diagrammatically in fig. 37.

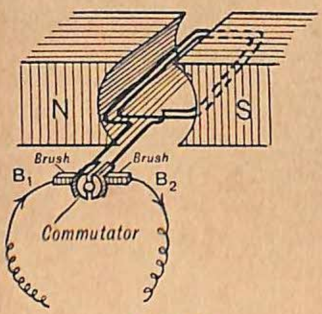
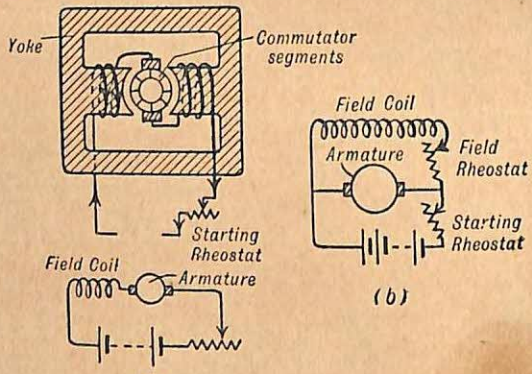


Fig. 36.



(a)

(b)

Fig. 37.—Types of D.C. motors

(*a*) *Series wound*, used for heavy work, *e.g.* traction, cranes, etc.
(*b*) *Shunt wound*, used for fairly steady work, *e.g.* driving lathes, etc.

In a **series motor** all the current passes in series through both field coils and armature. Series motors are used where variable speeds are necessary, as *e.g.* for electric trains and trams, and for cranes and hoists, etc.

In a **shunt motor** only part of the current passes through the field coils. Shunt motors are used where steady speed is necessary, as in workshops for driving lathes. You should now try to answer the following questions, giving reasons in each case:—

(1) *What would be the effect on the direction of rotation of an electric motor of reversing the current—*

(a) *in the armature only?*

(b) *in the field coils only?*

(c) *in both field coils and armature?*

(2) *How would you reverse the direction of rotation of a D.C. motor?*

The Moving Coil Galvanometer

A coil consisting of many turns of thin insulated wire is wrapped on a former, which is often a thin, hollow cylinder of metal, sometimes of iron. The coil is suspended from a metal support by a thin wire, which leads the current into the coil (fig. 38). The current passes out below the coil through a metal wire coiled into a loose spiral, and having a tiny mirror attached by means of a spot of wax. The coil hangs between the poles of a powerful horseshoe magnet. When a current flows through the coil a motor effect is produced, the combined lines of force of the magnetic fields of magnet and current being as shown in fig. 39. The coil tends to move round in the direction shown by the arrows. The rotation is opposed by the twist in the suspended wire and the coiling of the spring. The coil will be deflected until the controlling force balances the deflecting force. You should note that in

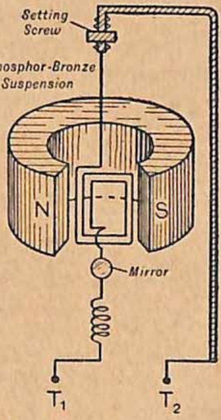


FIG. 38.—A moving coil galvanometer

this instrument there are **three essentials of any sensitive galvanometer.**

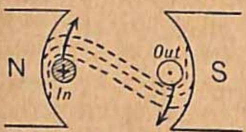


FIG. 39.—Section
Current flowing *in* ⊕.
Current flowing *out* ⊙.

(1) *The deflecting force is large.* It involves the strong magnetic field of the permanent magnet and the number of turns in the coil.

(2) *The controlling force is very small.* It is the force resisting twist in the suspending wire and spiral spring.

(3) *The pointer is very long and light;* in fact it is a beam of light which is reflected from the mirror and focussed on a scale some distance away so that very small deflections may be measured.

Some instruments of this type will measure currents of less than a hundred-millionth of an ampere.

Moving coil ammeters and voltmeters depend on the principle just discussed, but the current is led in through spiral springs similar to the hair springs of a watch, and the coil rests between pivots set in jewelled bearings. A light aluminium pointer attached to the coil moves over a scale when the coil moves. Usually the coil encloses a fixed cylinder of soft iron. This makes the lines of force radial, as in fig. 40, so that the angle of deflection of the coil is proportional to the current passing through it.

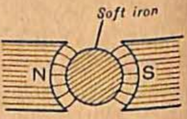


FIG. 40.

Moving coil loudspeakers also depend on the principles we have discussed.

QUESTIONS

1. A wire, free to move, hangs between two unlike poles. When an electric current is passed through the wire it moves. Draw diagrams to illustrate, and explain clearly the reasons why the wire moves.
2. Draw a diagram of a simple D.C. electric motor. Show the various parts, and explain their function.
3. How would you reverse the direction of rotation of a D.C. motor? Give explanation.
4. Describe a moving coil galvanometer and explain how it works. How may its sensitiveness be increased?

CHAPTER V

ELECTRO-MAGNETIC INDUCTION. THE PRINCIPLE OF THE DYNAMO. THE INDUCTION COIL. THE TRANSFORMER

An electric current cannot be set up without the expenditure of energy. In the case of a battery this comes from the energy released by the chemical action in the battery. The electrical energy in an electric circuit may be converted partly into heat in an electric lamp or in a wire, partly into mechanical energy as in the electric motor.

Experiments illustrating the Principle of the Dynamo

Make a coil by wrapping about 200 turns of insulated copper wire on a cardboard tube 3 or 4 in. long and an inch or so in diameter. Connect the ends to the terminals of a moving coil pointer galvanometer G (fig. 41) (one reading 2–0–2 milliamperes is suitable).[1] Stand the coil vertically on a bench and carry out the following experiments several times, making full notes of what happens :—

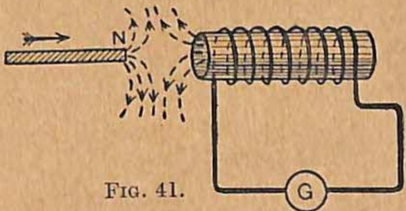


Fig. 41.

1. (*a*) Plunge into the coil the N. pole of a magnet.
   (*b*) Leave the magnet inside the coil for a few seconds.
   (*c*) Remove the magnet.
   (*d*) Repeat, using the S. pole.
2. Fix the magnet vertically in a wooden stand and then
   (*a*) Drop the coil on to the magnet ;
   (*b*) Remove the coil.

---

[1] Messrs Crompton, Parkinson & Co. supply a suitable instrument.

3. Find out if moving coil or magnet slowly or quickly has any effect on the current.

The current obtained is called an **induced current**, and the production of a current by the action of a magnet on a coil is called **electro-magnetic induction**.

The needle of the galvanometer moves to the right if the current flows into it at the terminal marked +. Knowing which way the coil is wrapped, repeat the experiments in order to find whether the induced current in the coil is clockwise or anti-clockwise when the magnet is inserted or removed, filling up the following columns :—

Pole	Induced current in coil is in	Thus the near face of the coil becomes
N. approaching . .	. . . direction	(N.) or (S.) pole
.. receding . .		
S. approaching . .		
.. receding . .		

These experiments show that when a pole is **approaching** the coil, the induced current produces a **like** pole at the near face ; when the pole is **receding** an **unlike** pole is produced at the near face. Thus to push the magnet into the coil you have to do work to overcome the repulsion of the like pole. In removing the magnet you have to do work to overcome the attraction of the unlike pole. The *mechanical work* done in these experiments *is converted into electrical energy*. No electrical energy can be produced without doing work.

The great English scientist, Michael Faraday, first performed these experiments in 1831. His work made possible the cheap generation of electrical energy on a large scale.

Another Experiment on the Principle of the Dynamo

Connect a wire to the sensitive galvanometer used in the last experiments (or to a moving coil reflecting galvanometer).

Move a straight piece of the wire between the poles of a powerful horseshoe magnet (fig. 42), and note the direction of the induced current when the wire is moving (*a*) up, (*b*) down. Verify that the magnetic lines of force when the wire is moving down are as shown in fig. 43 (*a*). Contrast these with the motor effect shown in fig. 43 (*b*).

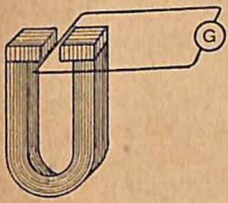
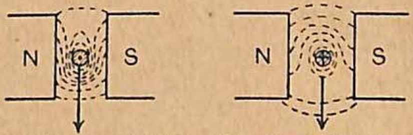


FIG. 42.



Wire pushed across against lines of force. Induced current up.

Current passed down the wire which is forced across.

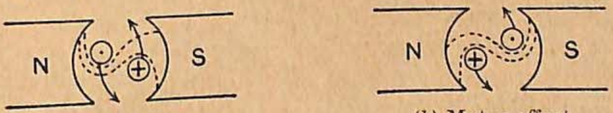
(a) Dynamo

(b) Motor

FIG. 43.

In the dynamo effect (fig. 43 (*a*)) the wire has to cut the magnetic lines of force, and the mechanical work done in cutting them is converted into the electrical energy of the induced current.

In the case of a coil which is forced to rotate between the poles of an electro-magnet, the lines of force are as shown in fig. 44 (*a*). Contrast these with the motor effect shown in fig. 44 (*b*).



(*a*) Dynamo effect

Coil *forced* round. *Induced current up* on left, *down* on right.

(*b*) Motor effect

Current passed *down* on left, *up* on right, *motion caused* in direction shown.

FIG. 44.

Again it is clear that **to produce the induced current, energy has to be expended in cutting the magnetic lines of force.**

How a Simple Dynamo Works

A coil of copper is rotated in the magnetic field between the poles of a magnet (see fig. 45). The ends are fastened to two copper rings fixed on the shaft, the rings and shaft being insulated from each other. Against each ring presses a carbon brush from which wires pass to the galvanometer G, whose pointer can swing left and right. When the coil is rotated at a uniform speed it cuts lines of force most rapidly when it is horizontal, *i.e.* in position *bd*. When it is vertical (as shown) it is not cutting lines of force at all. The galvanometer will thus register a current varying from a maximum to zero twice in each revolution. Also, as the coil rotates, the current will be first in one direction and then in the opposite direction, for during each revolution one end first passes up and then down. Thus the current is alternating. A.C.[1] machines work on this principle, the current being led into the external circuit through brushes which press against the rings.

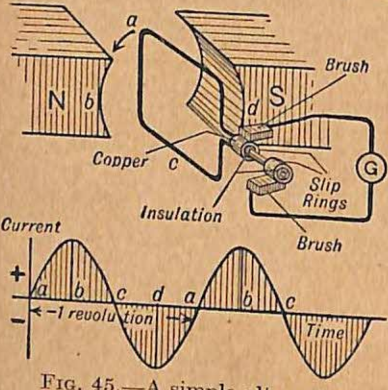


FIG. 45.—A simple alternator

If we require a D.C.[2] machine we must arrange for one brush to be always in contact with the left-hand side and the other with the right-hand side, no matter which ends of the coil are connected to the brushes. This is achieved by fastening the ends of the coil to a commutator consisting of two halves of a cylinder insulated from each other, instead of to the slip rings. As the coil rotates, each brush is in contact with each half of the commutator twice each revolution. The current generated still dies away to zero, but the current in the external circuit is now always in the same direction, *i.e.* it is D.C. The brushes change from one commutator segment to the other when the coil is midway between the poles (fig. 46). To obtain a steady current a large number of coils must be used and a correspondingly large number of commutator segments. The current in the brushes and in the external circuit is now the resultant of the currents in the several coils, each of which contributes something. With four coils the result is shown in fig. 46 and the current is almost steady but has a slight "ripple."

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[1] Alternating Current.

[2] Direct Current.

The earliest dynamos had permanent magnets, which were later replaced by electro-magnets excited by batteries. The great English electrical pioneer, Wheatstone, first showed that batteries were unnecessary, as there is always a little residual magnetism in the soft iron core, so that the dynamo may be made self-exciting by putting armature and field coils in series or parallel, according to the type of machine required. The armature coils are wound on a soft iron core built up from thin "stampings" which are insulated from each other by varnish. This is to reduce loss of energy due to "eddy currents" in the armature, for you must realise that currents will be induced in any metal which is rotated in a magnetic field. Two types of D.C. machine are shown diagrammatically in fig. 47 and their uses indicated.

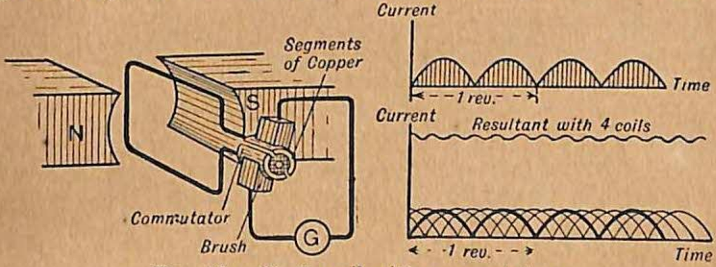
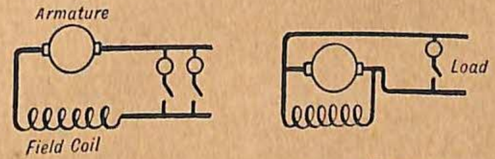


Fig. 46.—Single coil with commutator



Series dynamo Shunt dynamo

Fig. 47.—Types of D.C. dynamo

Series, now obselete
Shunt, used for lighting, etc., and work requiring a steady voltage

When the armature of a D.C. shunt dynamo is rotated it cuts the residual lines of force, and a small current is started in both armature and field coils. This causes the magnetic field to get stronger and stronger, until finally the iron gets saturated when the current reaches a certain value. To watch the readings of the voltmeter when the machine is "building up" is most instructive.

Further Experiments on Electro-magnetic Induction

Experiment 1

Make a second coil similar to the one described on p. 29 (fig. 41). Connect one of these coils, A, to a battery and a rheostat, and include a tapping key in the circuit (fig. 48). Place this coil above the other, B, which should be connected to a sensitive galvanometer, G. Verify that momentary induced currents are set up in coil B

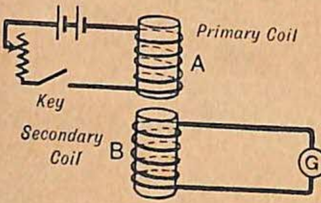


FIG. 48.

(*a*) When the current in A is started, or stopped,

(*b*) When the current in A is altered by means of the rheostat.

Insert a piece of soft iron inside the two coils and repeat the experiments. Explain the differences noted in each case.

Experiment 2

Wrap a few turns of copper wire round the core of a horseshoe electro-magnet in the circuit of which is a battery and a switch, S, and connect the ends to a galvanometer as shown in fig. 49 (*a*). Note the behaviour of the galvanometer when the armature is (i) pulled off, (ii) replaced. In this way the American scientist, Henry, first obtained an induced current a year before Faraday succeeded. Henry was a teacher and was only able to work in the

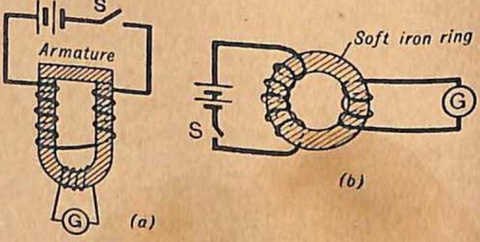


FIG. 49.—(*a*) Henry's apparatus
(*b*) Faraday's apparatus

vacations, and he put aside his work without publishing it, as his discovery was made at the end of a vacation. In the meantime Faraday discovered induced currents by means of the experiment now to be described. (It is interesting to note that Faraday and Henry had to wrap bare wire with silk to insulate it. They could not purchase insulated wire in those days.)

Obtain a soft iron ring about 6 in. in diameter and about $\frac{1}{2}$–1 in. thick. Wrap round it two separate coils of about 50–100 turns of insulated copper wire. Connect one (the *primary* coil) to a battery and switch, and the other (the *secondary* coil) to a sensitive galvanometer as shown in fig. 49 (*b*). Note the behaviour of the galvanometer needle when the current in the primary coil is (*a*) started, (*b*) stopped.

By continuing to start and stop the primary current an induced alternating current is set up in the secondary coil. The experiments you have just performed show the principle of the induction coil and the transformer, which will now be described.

The Induction Coil

This was invented in 1836 by an American, Charles Grafton Page. It consists of a primary coil of a few turns of thick insulated copper wire, wrapped round a coil made of a bundle of soft iron wires, insulated from each other (fig. 50). Round the primary coil is wrapped a secondary coil of thousands of turns of thin insulated copper wire, the ends of which are connected to a spark gap. Mounted against the core is an automatic make-and-break, which is in the primary circuit. The diagram shows a spring make-and-break. The contacts are of platinum or tungsten. A battery and switch are included in the primary circuit, which is exactly like the circuit of an electric bell. On closing the switch, the primary current flowing round the coil magnetises the core. The soft iron armature is attracted, breaking the circuit. The magnetic lines of force die away and the armature is pulled back by the spring. This closes the circuit again and the process is repeated. The rapidly changing magnetic field induces a high electrical pressure (voltage in the secondary) coil, and if this is high enough a spark passes across the spark gap. The higher the speed at which the magnetic lines of force are broken, the higher the induced voltage and the bigger the spark which can be obtained. Also, the greater the number of turns in the secondary coil, compared with the number in the primary, the greater the length of spark which may be obtained. A coil capable of giving a spark several inches in length may have several miles of wire in the secondary coil. A condenser is usually inserted across the make-and-break, as shown in the diagram. This consists of two sheets of tinfoil separated by a sheet of waxed paper so that the sheets of foil are insulated from each other—one sheet is connected to each end of the coil. In the diagram the right-hand side is connected to the coil through the battery when the switch is depressed. The condenser reduces sparking at the contacts and also speeds up the break, for it causes the magnetic field to die away much more rapidly than it would do if the condenser were absent.[1] As a result the secondary induced voltage at the "break" may be several times as great as at the "make," and the spark can jump a much greater gap at "break" than at "make." In this way the secondary **current** is caused to be pulsating, but always in the same direction, which is of great importance when the coil is used for X-ray work. Induction coils are used extensively in X-ray work, and have made possible the research

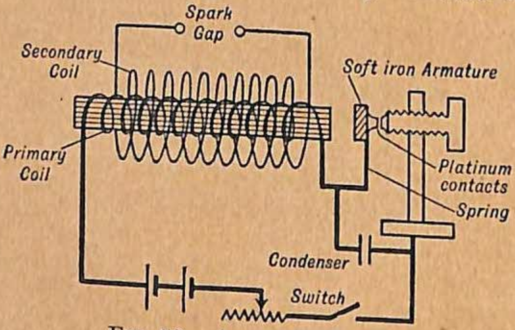


FIG. 50.—An induction coil

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[1] The mode of action of the condenser is too difficult to explain at this stage.

which has been done on the constitution of the atom. They are used for "coil ignition" on motor-cars and threaten to oust the magneto, which once ousted them when motor-car batteries were less reliable than they are at present.

The Transformer (fig. 51)

The core of a transformer, like the armature of an electric motor or a dynamo, is made from soft iron stampings. Transformers work entirely on A.C., and if put across D.C. terminals they may be burnt out. A.C. in the primary causes an alternating induced voltage across the secondary terminals, and if a lamp or other appliance is in the circuit a current flows. Fig. 51 shows a transformer diagrammatically.

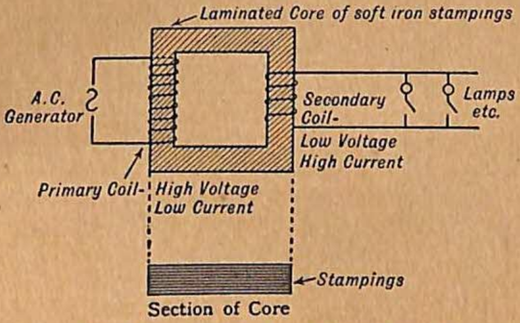

FIG. 51.—A step-down transformer

A **step-up transformer** has more turns on the secondary than on the primary coil. In a **step-down transformer** the reverse is the case. The terms "step-up" and "step-down" refer to the electrical pressure or voltage, and not to the current. It must be realised that the amount of electrical energy taken from the secondary side cannot exceed that taken in on the primary side. Now electrical energy, as you will learn later, depends on the *product* of the current and the voltage or pressure, and thus a transformer which "steps-up" the voltage will "step-down" the current.

Transformers of immense size are used extensively in the transmission of electrical power, and their design is the work of expert engineers and involves special study of the insulating properties of materials as well as special alloys used in the core. In the "grid" voltages of 132,000 used in long-distance transmission are stepped down in sub-stations, first to 33,000, then to smaller voltages, and finally to the usual 240 volts used in the household. The reasons why it is advantageous to transmit electrical energy as A.C. at a very high voltage will be explained in Part IV of this book. Small transformers are familiar in wireless sets.

QUESTIONS

1. Describe experiments illustrating the production of electricity by moving a magnet near a coil. Show by diagrams the direction of the induced current when the magnet (*a*) approaches, (*b*) recedes from the coil.
2. A coil of wire connected to a sensitive galvanometer lies on a table. When it is turned over quickly the galvanometer is deflected and then returns to zero. Explain this fully.
3. Describe Faraday's experiments which led to the invention of the transformer.
4. Describe how an iron-core transformer is made up. Draw clear diagrams to show the directions of the currents in the secondary coil when the primary current is (*a*) increasing, (*b*) decreasing.
5. Describe a simple form of dynamo and explain how it works.
6. Describe the construction and action of an induction coil.
7. Fig. 52, shown, represents a dynamo—copy it. Name the principal parts and complete the connections so that it is a shunt machine. Include a field rheostat in the circuit.

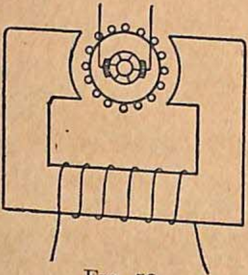

FIG. 52.

CHAPTER VI

THE REFLECTION OF LIGHT FROM PLANE SURFACES

Introduction—Every schoolboy at one period of his career tries to annoy an elderly gentleman by reflecting sunlight into his eyes from a piece of looking-glass. Who has not been dazzled momentarily by sunlight reflected from the glass windscreen of a motor-car, which happened to "catch the sun" as it approached ?

Our eyes enable us to see objects, but unless light comes from the objects to our eyes we cannot see them. Bodies such as the sun and the "fixed stars," lighted candles and glowing lamps emit light and are self-luminous ; but other bodies are seen by means of light which they reflect. The moon and the planets, also the trees and hills of the ordinary landscape, do not emit light of themselves, but are visible to us because of the sunlight which is reflected from them.

Simple Experiments on the Reflection of Light

For experiments in light it will be convenient to use one of the many excellent ray-boxes now on the market.[1] One of the most convenient is the Stephenson ray-box,[1] shown in fig. 53. It contains a motor headlight lamp, the filament of which is a very fine straight spiral which hangs vertically, and which emits a very intense light when illuminated by means of an electric current.

Several ray-boxes may be worked from the output side of a 240/12-volt transformer by means of sets of six lamp-holders wired in parallel (fig. 54).

The ray-box should be set up on a sheet of white paper. Insert the cylindrical lens in the slot as shown. Drop a multiple slit in another slot, in front of the lens. Move the light to and fro, and note that you may obtain at will converging, diverging, or parallel rays. Arrange so that parallel rays are produced. Replace the multiple slit by a single slit.

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[1] Such are the "Stephenson" ray-box, sold by Messrs Dick, Son & Lewis; the "Lambeam" apparatus, sold by Messrs Philip Harris & Co., Ltd.; the "Meier" optical set, sold by Messrs Philip Harris & Co., Ltd. For experiments at home the "Construments" optical set is excellent.

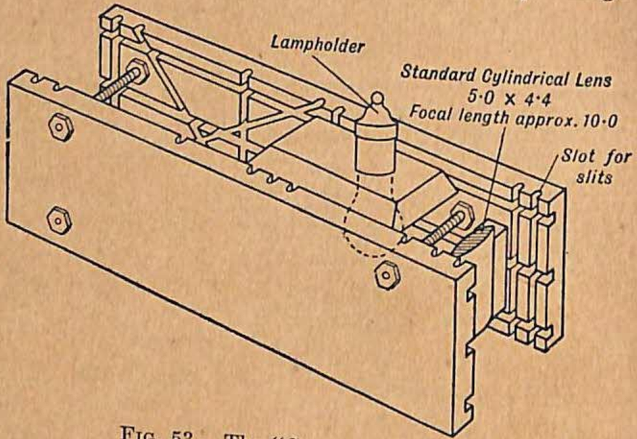

FIG. 53.—The "Stephenson" ray-box

Strips of thin plane mirror about 4 in. × 1 in. should be cut away from a cheap looking-glass, which may be bought for a few pence. These may be stuck with seccotine to rectangular slabs of wood or fixed into slits on corks.

Set up one of these strips so that it passes through the centre of a circular scale of degrees on a white card and is at right angles to the 0° mark. Arrange for the ray of light to strike the mirror at the centre of the scale. Note the angles of incidence and reflection, which are measured from the normal (see fig. 55). Repeat several times with different angles of incidence. Do not fail to send a ray along the normal, where the angle of incidence is 0°.

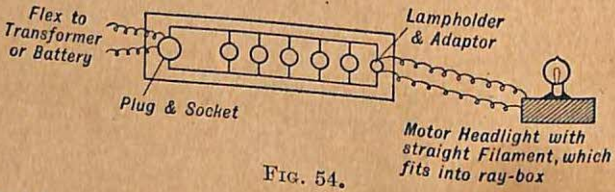
Flex to Transformer or Battery
Lampholder & Adaptor
Plug & Socket
Motor Headlight with straight Filament, which fits into ray-box

FIG. 54.

Tabulate your results thus:

Angle of incidence	Angle of reflection
degrees	degrees

The experiment shows that **when a ray of light is incident on a plane mirror the incident and reflected rays make equal angles with the normal.**

This is the **First Law of Reflection of Light.**

Now arrange to look along the bench into the mirror. You will see an image of the white card. By tilting the mirror verify that *only when the mirror is perpendicular to the card the image of the card is in the same plane as the card itself*. This verifies the **Second Law of Reflection of Light,** which is stated thus:

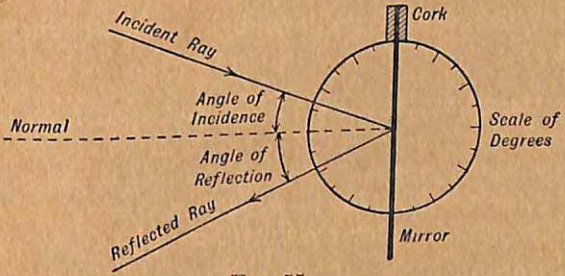

FIG. 55.

The incident and reflected rays are in the same plane as the normal.

Ground Glass—The surface of a piece of ground glass is not smooth but very irregular—*what effect will this have on a beam of light which falls on it?* Try to draw a diagram to illustrate. **What is the effect on the reflection of light of wetting the ground glass?**

The appearance of ground glass is often described as being due to irregular reflection. *Do you agree with this?* Give reasons.

The illuminated signs often displayed on motor-cars in daylight utilise the reflection of light by a plane mirror (fig. 56). This is directed on to the sign, which is made of translucent material—*i.e.* rough material which transmits light but through which, as through ground glass, a clear image cannot be seen.

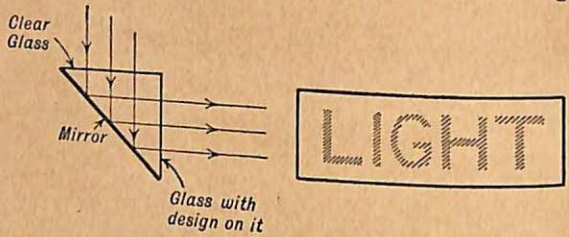

FIG. 56.—An illuminated sign

An Experiment on the Effect of Rotating a Mirror on Reflected Light

Set up the mirror as before so that an incident ray falls on it. Note the position of the reflected ray. *Keeping the incident ray fixed*, rotate the mirror through 5°, 10°, 15°, etc. Each time note the angle turned through by the reflected ray. What do you find?

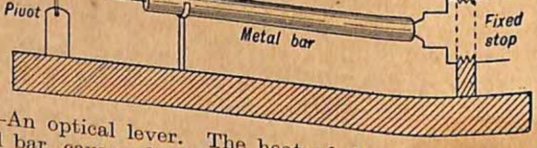

FIG. 57.—An optical lever. The heat of the hand, placed near the metal bar, causes slight expansion which is made visible by the mirror system shown

If the ray is incident on a mirror, through what angle will the reflected ray turn if the mirror turns through 20°?

A beam of light reflected from a very small mirror is often used as a pointer to measure very small movements. If the beam is intense the reflection may be made to fall on a screen many feet distant, and the slightest movement of the mirror then causes quite a measurable deflection of the light on the scale. This is utilised, for instance, in delicate mirror galvanometers used to detect tiny electric currents (see p. 27 (fig. 38)). Its use in an **optical lever** is shown in fig. 57.

The Solar System—When you look out on a clear night you will observe that most of the stars twinkle, but that there are a few bright stars which do not twinkle.

If you observe the stars night after night you will find that those which do not twinkle move slowly amongst the rest, which always appear to make the same pattern in the sky, although as the nights pass by their times of rising and setting gradually alter. These stars are called "fixed" stars, because for ages there has been very little perceptible movement amongst them. The few stars which appear to move amongst the rest were called *planets* (wanderers) by the ancients, and we know now that they belong to a family of stars called the solar system, of which our earth is a member and the sun is the centre. The planets move round the sun, and the moon, which is a satellite of the earth, moves round the latter. A remarkable thing about the planets is that they shine, not by their own light, but because of the sunlight which they reflect in all directions, as does a sheet of ground glass. The varying phases of the moon are due to only part being illuminated by the sun. When the moon is not fully illumined—for example, when it is crescent-shaped—on a clear night you may observe that the dark part is faintly illuminated. This is due to its catching some of the sunlight which is reflected from the earth. The fixed stars are usually suns like our own, some very much larger, and at tremendous distances from us.

So far away are they that their distances are given by astronomers in "light-years." A light-year is the distance light travels in a year. As light travels 186,000 miles in a *second*, a light-year is an immense distance. You should calculate how many miles it is. The sizes and distances of the planets from the sun are given in the following table.

	Mean distance: millions of miles	Diameter: miles	Period of Revolution approx. years
Sun	0	866,400	
Mercury	36	3,030	0·24 years
Venus	67·2	7,700	0·62 ,,
Earth	92·9	7,918	1·00 ,,
Mars	141·5	4,230	1·88 ,,
Jupiter	483·3	86,500	11·86 ,,
Saturn	886	73,000	29·50 ,,
Uranus	1782	31,900	84·00 ,,
Neptune	2792	34,800	164·80 ,,

Calculate the number of light-years Jupiter is from the sun, and compare this with the distance of Alpha Centauri, the nearest fixed star, which is over 4 light-years from us. You will realise how empty space is.

Jupiter is a beautiful sight when observed with a pair of field glasses. It has four clearly visible moons (and several others also), which all appear in line with each other and with Jupiter, and which are moving round Jupiter in varying periods. Uranus and Neptune are not visible without the aid of a fairly large telescope. Mercury is rarely seen with the naked eye, but may occasionally be observed soon after sunset setting rapidly in the west.

Images in Plane Mirrors

Method 1—Set up the motor headlight lamp with its filament vertical and about 3–4 in. from a thin strip of mirror (fig. 58). The latter should be fixed vertically with its back on a line drawn on a sheet of paper affixed to a cork mat. By inserting a comb or a multiple slit between the lamp and the mirror a series of incident and reflected rays will be seen and their positions marked. Look along the reflected rays. Each appears to proceed from the image of the filament, and by producing them backwards the position of the image is found.

Join O and I. *Is this line normal to the mirror? What do you notice about the distances OM and MI?*

These should be sufficiently close to enable a conclusion to be drawn.

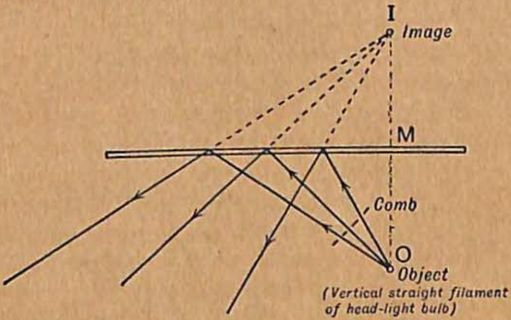

Fig. 58.

It is seldom that object and image distances are found to be exactly the same for several reasons :—

(*a*) Errors of observation.
(*b*) ,, in measurement.
(*c*) ,, due to the mirror being silvered on the back.

The fact that several observations of each distance add up to approximately the same gives a strong probability to the conclusion that

The image is as far behind a plane mirror as the object is in front.

You should try to realise that no measurement can be exact for the reasons (*a*) and (*b*) just given. Thus no law can be *exactly* verified, but the more times an experiment is found to give approximately the same result, the more probable is the fact suggested by the experiments.

Method 2—**The method of coincidence or no-parallax** (fig. 59). Consider two pins, A and B, observed from various positions, X, Y, Z, etc. To an eye at X they appear to be apart, and the angle BXA is called the angle of parallax. The angle AYB is the angle of parallax to an eye at Y. From Z, which is in

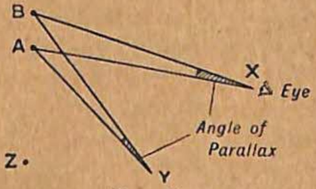

Fig. 59.

line with AB, the angle of parallax is 0°. We say that at Z there is no parallax between A and B.

If *A and B happen to coincide with each other there will be no parallax from whatever position they are viewed.* Verify that if your eye is at Y and you move to the right, the *more distant* pin B appears to move to the right also.

Set up a plane mirror with an object pin in front. Look into the mirror and place a knitting needle behind (fig. 60). Observe this over the top of the mirror, and move it about until eventually it appears in line with the image from all points of view. There is then no parallax between the needle and the image and the needle marks the image position. Verify that the image and object are equal distances from the mirror.

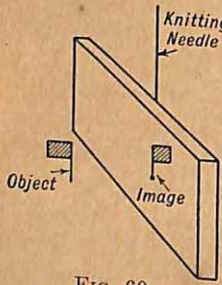

FIG. 60.

If you wish to see an image of the back of your head you look into a fixed mirror and move a small hand mirror about behind your head. This will be better understood after doing the following experiment.

Images in Two Mirrors placed at an Angle to Each Other

Place a pin in front of two mirrors A and B (fig. 61), A being fixed and B movable to make various angles with A. Commence with the mirrors at 180°. *How many images do you see?* Gradually decrease the angle between the mirrors. At first you will see two images, but as the angle between A and B gets less these change to three, four, etc. Try to find the angles at which the changes take place, tabulating as shown on the following page.

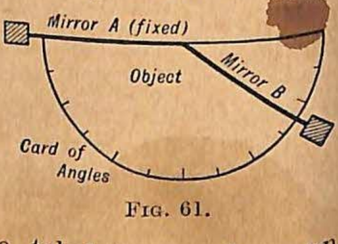

FIG. 61.

Observe the number of images of the mirrors also. Observe that every time a new image of the pin appears, a fresh mirror image appears as well. It is as though the angle of 360° is divided into spaces in one of which is the object and in each

Angle between mirrors	No. of images
From 180 to 120	2
,, 120 ,, 90	3
,, 90 ,, ..	..
..	..
..	..
..	7

of the others an image. *What difference is there in the brightness of the images when there are several ?*

The images after the first are formed by rays from the object being reflected two, three, four, etc. times from the mirrors. This will be clearer after making drawings to scale. At each reflection some light is lost, being absorbed by the glass. Thus, as the angle between the mirrors is reduced, making more images, the added images get fainter and fainter owing to loss of light as the reflections increase in number.

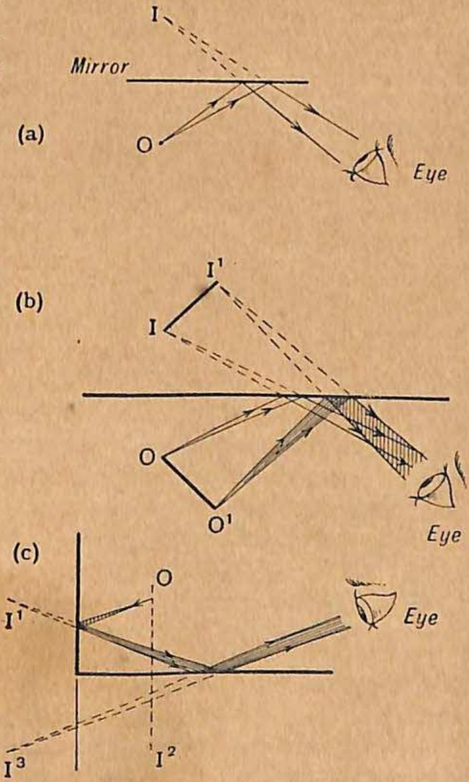

FIG. 62.

Scale Drawings to show how the Eye sees Images in Plane Mirrors (fig. 62)

(*a*) **The image I of a point O viewed in a**

plane mirror—I and O are equidistant from the mirror along a normal. The eye intercepts a *cone* of rays which is reflected as shown.

(*b*) **The image of an extended object in a plane mirror**—Cones of rays are shown from the ends of the object only. Notice the lateral inversion which occurs, so that the image of your left hand appears as a right hand.

(*c*) **The images in two mirrors at 90°**—The cone of rays is shown which forms the middle image only. It is evident that the light has been reflected twice.

(*d*) **To see an image of the back of your head.**

This is achieved by placing a hand mirror behind the head and moving it about until an image of the back of the head is seen in the fixed mirror. Fig. 62 (*d*) shows how this image is formed.

The point of the V represents the back of the neck.

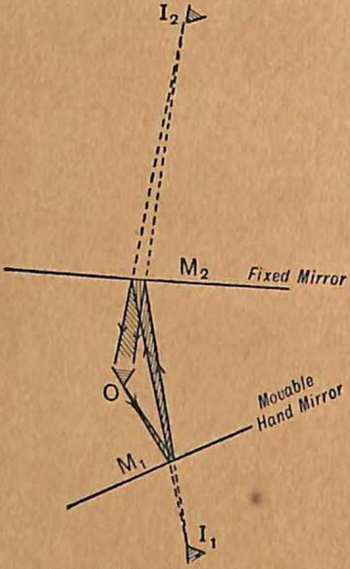

FIG. 62 (*d*).

I_1 is the image in the movable mirror. $OM_1 = M_1I_1$.

I_2 is the image of I_1 in the fixed mirror. $I_1M_2 = M_2I_2$.

The direct image of O in M_2 is omitted so that attention may be concentrated on the image I_2. A cone of rays from the point of the V is shown. I_2 is formed by two reflections.

An interesting use of mirrors placed at an angle is the toy called the kaleidoscope.

The Kaleidoscope

Into a cardboard tube about a foot or fifteen inches long fix three strips of plane mirror at about 60° to each other with plasticine or sealing-wax (fig. 63). At one end of the tube fix a piece of waxed paper or ground glass on which are some loose pieces of coloured glass or celluloid. Fit a card with a peep-hole at the top end, and view a white card, holding the instrument at a few degrees to the vertical. Rotate the instrument and watch the marvellous patterns change.

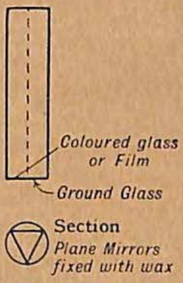

FIG. 63.—The Kaleidoscope

A Simple Periscope

You may make a simple periscope by fixing two mirrors, A and B, in a long cardboard tube as shown in fig. 64. The mirrors should be fixed at 45° to the axis of the tube, and holes should be cut in the cardboard opposite the mirrors as shown. An eye placed at E will then see images of objects by reflection in the mirrors A and B. Periscopes made on a similar principle were used in the Great War by soldiers in the trenches. These and also submarine telescopes are usually fitted with lenses so that magnified images are obtained.

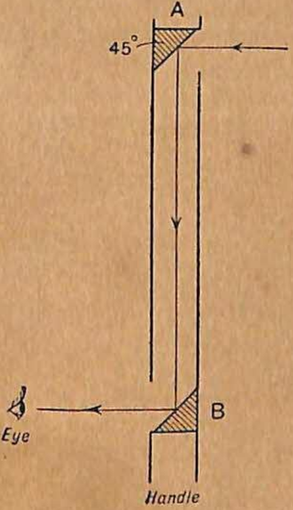

FIG. 64.—Simple periscope

QUESTIONS

1. State the laws of reflection of light. Illustrate by a diagram showing an incident and a reflected ray, the normal, and the angles of incidence and reflection.
2. Explain why a plane mirror gives an image whereas ground glass does not.
3. A ray of light falls normally on a plane mirror. The mirror is then turned through 20°. By drawing find the angle through which the reflected ray turns.
4. Draw a diagram showing a point object 2 in. from a plane mirror. Draw three rays of light from the object to the mirror and show by accurate drawing that the reflected rays all pass through one point.
5. Describe and explain how you would find the position of the image of a point object by the method of coincidence.
6. Draw two mirrors inclined (*a*) at 90°, (*b*) at 60°. Place a point as object between each and show accurately the position of all the images formed.
7. What is "lateral inversion"? Illustrate by a diagram.
8. Show how by means of a fixed and a movable mirror you can see an image of the back of your head.

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CHAPTER VII

EXPERIMENTS WITH LENSES AND CURVED MIRRORS

Everyone has seen a searchlight, which uses a curved mirror to reflect the beams of a powerful arc-light, and most children have tried to set fire to a match or a piece of paper by means of a burning glass. A flask full of water makes a good burning glass. Place one on the edge of a stool in the sunlight and hold a piece of paper at the spot on which the emergent rays are concentrated. Fires are known to have been caused in this way through a glass bottle full of water concentrating the sun's rays on to dry heather or grass during a drought. The uses of lenses in cameras, microscopes and telescopes, and of curved mirrors in motor-cars, are familiar to all. We shall now study the principles on which the use of lenses and curved mirrors depend. For use with the ray-box half-lenses and mirrors are provided which stand vertically on the bench. Various types of lenses are shown in fig. 65.

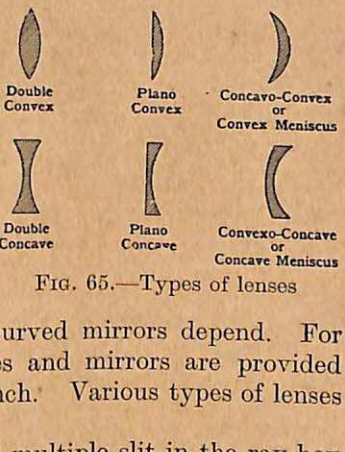

Double Convex
Plano Convex
Concavo-Convex or Convex Meniscus
Double Concave
Plano Concave
Convexo-Concave or Concave Meniscus

Fig. 65.—Types of lenses

Insert the cylindrical lens and multiple slit in the ray-box and arrange for the emergent rays to be parallel. The filament is then at one **principal focus** of the lens.

Stand a half-convex lens [1] on the paper in the path of the parallel rays (fig. 66). These are now made to converge to one of the **principal foci** of the lens. Measure the distance of this principal focus from the lens. Turn the lens round and repeat. The distance you measure in each case is the

---

[1] A lens cut along a diameter so that it will stand up on the bench.

focal length of the lens. Repeat, using a plano-convex lens. In each case you find that **the two principal foci are at approximately the same distance from the lens.**

The reason *why* the lens bends the rays will be understood later.

Repeat these experiments, allowing the rays to fall on half a concave lens (fig. 67). In this case the rays are caused to *diverge* by the lens. The principal focus is found by producing the emergent rays backwards. Parallel incident rays are bent by a convex or **converging** lens, so that they actually pass through the principal focus. In this case the principal focus is said to be **real.** In the case of the concave or **diverging** lens parallel incident rays are bent so that they diverge from the principal focus. Such a principal focus is said to be **virtual** or **imaginary.**

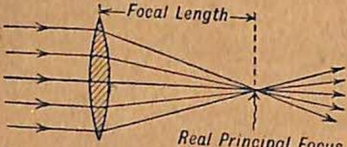


Fig. 66.—A convex or converging lens has real principal foci

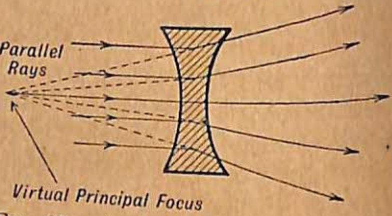


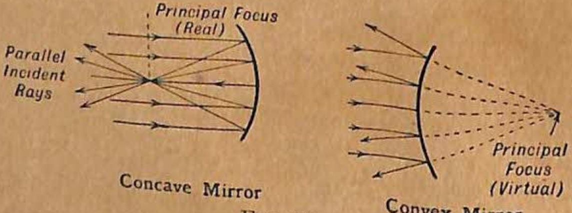
Fig. 67.—A concave or diverging lens has virtual principal foci

Perform Similar Experiments using

(*a*) **A concave or converging mirror.**

(*b*) **A convex or diverging mirror.**

Measure the focal length in each case and say whether it is real or virtual (fig. 68).



Concave Mirror

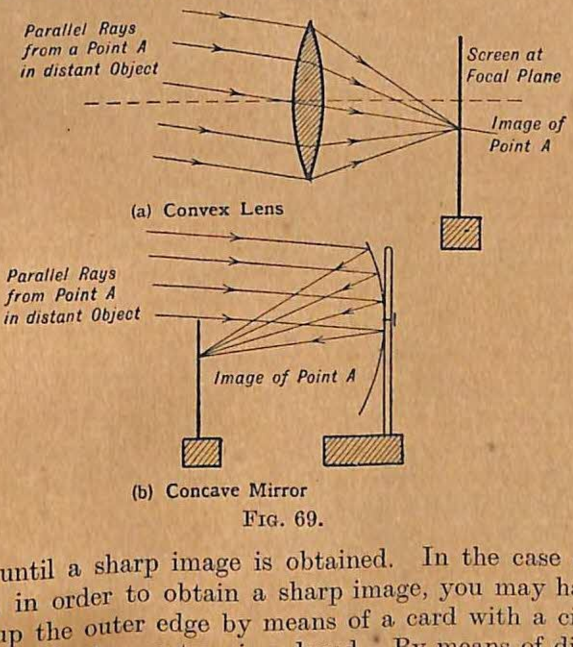
Convex Mirror

Fig. 68.

The principal focus of a lens or a curved mirror is the point through which rays parallel and near to the axis pass or from which they appear to diverge after leaving the lens or mirror. If the emergent or reflected rays actually pass through the principal focus it is **real**; if they do not, it is **virtual.**

Other Methods of finding the Focal Lengths of a Concave Mirror or a Convex Lens.

By using a distant object—Place the lens or mirror in a holder at a great distance from a lighted window and move a screen about until a sharp image is obtained. In the case of the mirror, in order to obtain a sharp image, you may have to cover up the outer edge by means of a card with a circular hole, so that the aperture is reduced. By means of dividers measure the distance from the lens or mirror to the screen. Repeat the experiment several times, and find the average result for (*a*) lens, (*b*) mirror.


Parallel Rays from a Point A in distant Object
Screen at Focal Plane
Image of Point A
Parallel Rays from Point A in distant Object
Image of Point A

(a) Convex Lens

(b) Concave Mirror

FIG. 69.

As the object is a great distance from the lens or mirror, rays reaching them from a point on the object are practically parallel and will come to a focus in the focal plane. This will be understood from fig. 69.

Focal Length of a Convex Lens using a Plane Mirror

Cut out a small triangular hole in a piece of cardboard and set it up near a light so that it forms an illuminated object for the lens (fig. 70). Place a plane mirror behind the lens (use a piece of soft wax), and move them about until the image of the triangular hole is clearly focussed beside the hole. Arrange for one apex of the triangle to touch its image. The rays from this point must have passed along the same path after reflection in the mirror. The rays from the lens to the mirror must therefore be parallel. Thus the point considered must be a principal focus of the lens.

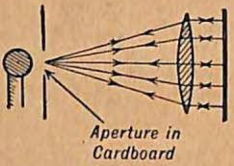


FIG. 70.

To find the Radius of a Concave Mirror

Set up a concave mirror on a bench and try to manœuvre a knitting-needle on a stand until the image of the point coincides with the point itself (fig. 71). To do this, look down on the mirror from a distance and try first with your finger. By moving the finger up and down you will find the approximate position, and then the finger should be replaced by the pin, which, with a little practice, can be set so that the point is at the exact position. Measure the distance from the mirror to the pin. This is the radius. All the rays from the point have been reflected along the same path. They must therefore be at right angles to the mirror surface everywhere, and thus the point is the **centre of curvature** of the mirror.

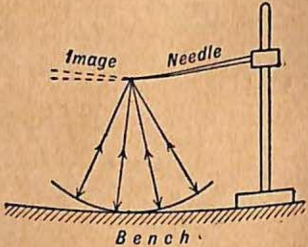


FIG. 71.

The radius may also be found by setting up the mirror so the rays from the ray-box are directed towards the mirror after passing through a lens. By manœuvring the lens you can reflect the rays from the mirror along their own path as in fig. 72. The radius is then easily measured.

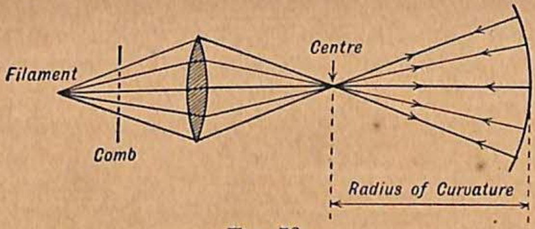


FIG. 72.

Measure the radius and the focal length of several concave mirrors by the methods described.

Arrange your results thus :

Mirror No.	Radius cm.		Focal length cm.		$\frac{\text{Radius}}{\text{focal length}}$
		Mean		Mean	
1	(*a*) .. .. (*b*)	..	(*a*) .. .. (*b*)	..	

What is the relation between the radius and the focal length?

Caustic Curves

The middle point of the surface of a curved mirror is called the *pole*. The *normal* to the surface through the pole is called the *principal axis*. The *principal focus* lies on the principal axis. The *focal plane* is a plane through the focus perpendicular to the principal axis.

If you set up a semi-cylindrical mirror on a sheet of white paper so that the sun shines on it you will observe a brilliant curve called the *caustic curve* very clearly (fig. 73). On interposing a comb the rays forming the caustic become visible. You may observe this curve on the surface of a cup of tea which stands in the sunlight.

On a sheet of paper draw a semicircle two inches radius to represent the section of a large concave mirror. Draw several lines a quarter of an inch apart, parallel to the principal axis. These represent incident rays. Let AB in fig. 73 be such a ray. Join B to the centre C, the tiny bit of mirror at B may be considered to be plane, and BC is normal to it. Make the angle of reflection, CBD, equal to the angle of incidence, ABC. BD is then the reflected ray. It will be noticed that if B is far from the pole P, the ray BD meets the mirror and is again reflected. Repeat the above for all the lines. You will observe that only those incident rays which are near the axis are reflected through the principal focus F. Therefore only that part of the mirror shown as a thick line should be used if good images are to be obtained. All the rays are tangential to a *caustic curve*, shown by thick lines in fig. 73.

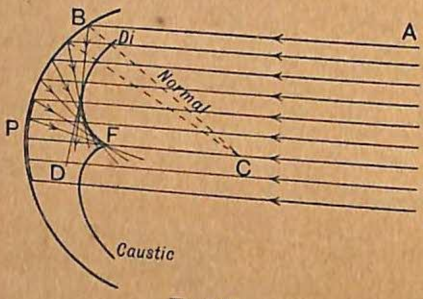


Fig. 73.

Thus for accurate work with curved mirrors only the small portion near the pole should be used.

Graphical Study of the Positions of Images in Curved Mirrors

The position of the image may be found with a fair degree of accuracy from a drawing to scale.

Since we only deal with rays near the axis it is sufficiently accurate to draw a vertical line for the mirror, but a curved dotted line should be shown to indicate the type of mirror.

The following rays should be used :—

(*a*) A ray through the centre, which is a normal and gets reflected back along the same path.

(*b*) A ray parallel to the axis, which is reflected through the focus.

(*c*) A ray through the focus, which is reflected parallel to the axis.

Any two of these will be sufficient to find the position of the image.

Images through which rays actually pass are *real* images and may be obtained on a screen. All images in front of a mirror are real.

Images which are *behind* a mirror are *imaginary* or *virtual*, and real rays do not pass through them.

The diagrams which follow will show the method. A suitable focal length is 8 cm., and height of object 2 cm. Squared paper is convenient, as it enables the work to be done to scale very quickly and accurately.

1. Object outside the centre (fig. 74) (say 12 cm. from the mirror).

Image is (1) Real ;
(2) Inverted ;
(3) Smaller than object.

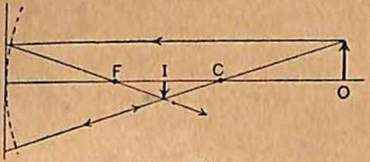


FIG. 74.

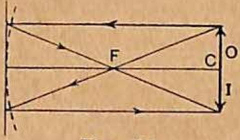


FIG. 75.

2. Object at the centre (fig. 75).

Image is (1) Real ;
(2) Inverted ;
(3) Same size as object.

3. Object between C and F (fig. 76) (say 6 cm. from the mirror). Drawing is like fig. 74 but with O and I reversed.

Image is (1) Real ;
(2) Inverted ;
(3) Magnified.

4. Object at F—Verify that rays after reflection are parallel.

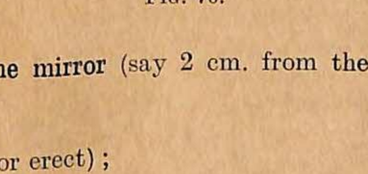


FIG. 76.

5. Object between F and the mirror (say 2 cm. from the mirror) (fig. 76).

Image is (1) Virtual ;
(2) Upright (or erect) ;
(3) Magnified.

Summary

Suppose you approach a concave mirror along the axis from a long distance, what happens to your image ? At first it is very small, inverted, real, and near the focus. As you move towards the centre the image moves very slowly towards you, increasing in size until when you are at the centre it is the same size and under your feet. Then as you move towards the focus, the image moves away behind you faster and faster, meanwhile getting larger and larger until when you are at the focus the image is at infinity and of an infinite size. As soon as you step inside the focus the image is virtual, appearing behind the mirror greatly magnified, upright, and comes towards you as you go towards the mirror.

Convex Mirrors

You should now do a series of drawings for a convex mirror. This time the focus and centre are behind the mirror, and so is the image, which will be found to be always

(1) Virtual ;

(2) Smaller than the object ;

(3) Between the focus and the pole.

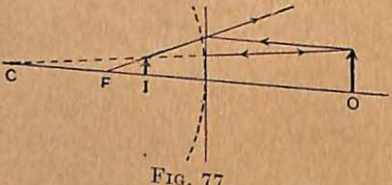


Fig. 77.

The method of construction will be understood from fig. 77. **Thus a convex mirror can never give a real or magnified image.**

Applications of curved mirrors—Convex mirrors are used on motor-cars to show the driver the traffic which is behind him. Their advantage over a plane mirror is that they show a larger field of view, which is hardly altered by movements of the driver.

These points are made clear by fig. 78. If BD is a convex mirror the field of view is between the extreme rays BA and DC. With a plane mirror of the same size (shown by the dotted line BD) the field of view is only between BF and DG.

A Searchlight consists of a curved mirror at the focus of which burns a powerful arc-light. A spherical mirror is not used owing to the fact, already mentioned, that reflected rays some distance from the pole are not parallel. This trouble is overcome by forming the mirror in the shape of a hollow paraboloid instead of a sphere. Then all rays from the focus are reflected parallel to the axis. The beam thrown out by a searchlight would be perfectly parallel if the light emerged from a point, but in practice the light comes from a small area on the positive carbon of the arc, and so spreads over a few degrees on each side of the axis.

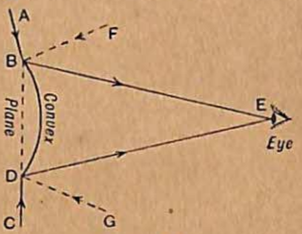


FIG. 78.

Graphical Work on Lenses

The principal axis of a lens is a straight line through the centres of the spheres of which the lens surfaces form parts.

The optical centre of a lens is the point on the principal axis through which all rays pass without deviation. This is point C in fig. 79.

As we are dealing with thin lenses, rays will be drawn to a line through the optical centre and perpendicular to the axis as in figs. 79–82.

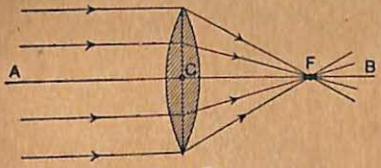


FIG. 79.

In the diagram (fig. 79) AB is the axis, C the optical centre, and F the *principal focus*, or simply the focus. Lenses have two principal foci, equidistant from the optical centre.

In finding the position of the image we can use the following facts :—

(*a*) Rays parallel to the axis converge towards or diverge from the focus after refraction.

(*b*) Rays through a focus are parallel to the axis after refraction.

(*c*) Rays through the optical centre C pass straight on.

The following diagrams will show how these principles are applied. A suitable focal length is 4 cm., and the object size should be 2 cm.

Convex or Converging Lenses

1. Object outside 2F′ (fig. 80) (say 12 cm. from the lens).

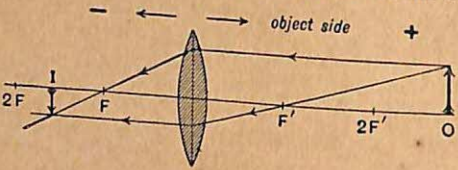


Fig. 80.

Image is (*a*) Real ;
(*b*) Inverted ;
(*c*) Smaller than the object ;
(*d*) Between F and 2F.

2. Object at 2F′

Image is (*a*) Real ;
(*b*) Inverted ;
(*c*) The same size as the object ;
(*d*) At 2F.

3. Object between 2F′ and F′ (say 6 cm. from the lens). As in (1), but a magnified image and outside 2F.

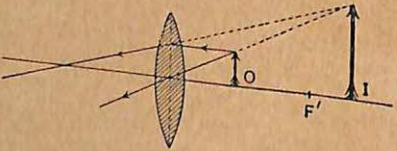


Fig. 81.

4. Object between F′ and the lens (say 2 cm. from the lens) (fig. 81).

Image is (*a*) Virtual ;
(*b*) Erect ;
(*c*) Magnified ;
(*d*) Behind the object, on the object side of the lens.

That there is a remarkable analogy between a convex lens and a concave mirror is now clear. The reader should write down for himself what happens to his image when he walks from a distance towards a convex lens.

You should remember that :

(*a*) For a magnified real image O is between F′ and 2F′.
(*b*) For a magnified virtual image O is between F′ and the lens.

(*a*) is applied in the magic lantern, cinematograph, enlarging camera, etc., (*b*) is applied in the simple magnifying glass, microscope, etc.

Concave or Diverging Lenses

A concave lens behaves very like a convex mirror, and you should verify that the image is always

(*a*) Virtual ;
(*b*) Erect ;
(*c*) Diminished ;
(*d*) Between F and the lens (fig. 82).

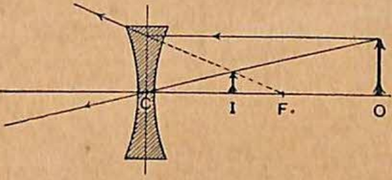


FIG. 82.

Worked examples—Straightforward problems may be solved by the methods already given. The following example is a little more difficult and is worked in full.

A convex lens of 10 cm. focal length forms an image twice as big as the object. Where must the object be placed?

(*a*) **Real image**

Let the object be three small squares high. Draw AB (fig. 83) parallel to the axis. This passes through the top of the object, is refracted through F, and will pass through the top of the image. As the latter is twice the size of the object it will be at D, where ID = six small squares.

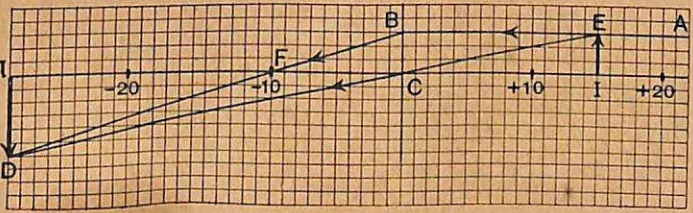


FIG. 83.

Now draw from D to C. This will meet AB in the top of the object, which will consequently be at E, 15 cm. from the lens.

(*b*) **Virtual image** (fig. 84).

In this case proceed as before, but D will be on the object

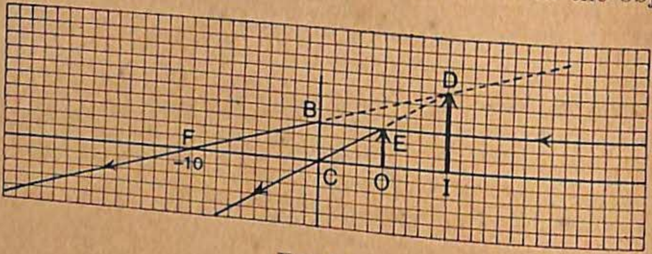


FIG. 84.

side of the lens and six small squares high. E is found to be 5 cm. from the lens.

Further Experimental Work on Curved Mirrors and Lenses

Find the focal length of (*a*) a concave mirror, and (*b*) a convex lens.

Using the illuminated triangular hole in a sheet of cardboard as object, verify by experiments the facts you have discovered in the course of your graphical work, placing the object at various distances from the mirror or lens. Tabulate your results thus:

Concave Mirror

Focal length = cm.

Distance of object from mirror	Distance of image from mirror	Type of image (real, inverted, magnified, or diminished)

Virtual images—To find the position of a virtual image in a convex lens, place a pin for an object about half-way between the lens and the principal focus. The image is seen to be magnified and on the same side as the object. Looking through the lens at the pin, try to manœuvre a knitting needle until the part *above* the lens always coincides with the *image* of the pin when the head is moved about.[1] This requires a little practice, but fig. 85 will help you to understand how it is done.

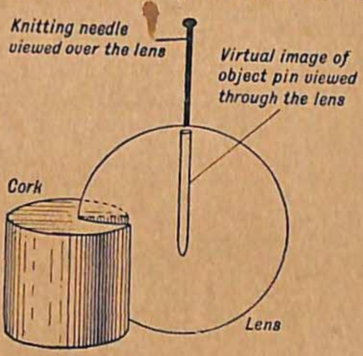

Knitting needle viewed over the lens
Virtual image of object pin viewed through the lens
Cork
Lens

FIG. 85.

A similar procedure may be followed in the case of a concave or convex mirror, the difference being that the virtual images in this case are *behind* the mirror. You should verify that *for a convex mirror the images are always virtual and erect,* but for a concave mirror the image is only virtual when the object is between the mirror and the principal focus.

QUESTIONS

1. Draw diagrams showing what happens to parallel rays falling on both types of curved mirrors and lenses. In each case state if the principal focus is real or virtual.
2. Describe two methods of finding the focal length of a convex lens.
3. How could you find the positions of (*a*) the centre, (*b*) the principal focus, of a concave mirror? What relation exists between the focal length and the radius of curvature of such a mirror?
4. Find by careful drawing the position and nature of the image of an object 2 cm. high placed (i) 12 cm., (ii) 6 cm., (iii) 2 cm. from a concave mirror of 8 cm. radius.
5. Repeat (4) for a convex mirror of the same radius.
6. Repeat (4) for a convex lens of focal length 4 in.

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[1] Method of no-parallax, see p. 45, fig. 59.

7. Repeat (4) for a concave lens of focal length 4 in.
8. What advantage has a convex mirror over a plane mirror on a motor-car? Illustrate by diagrams.
9. A concave mirror, radius 10 cm., forms an image twice as big as the object. Find by drawing the position of the object when the image is (*a*) real, (*b*) virtual.
10. A convex lens, focal length 12 cm., forms an image three times as big as the object. Find by drawing the position of the object when the image is (*a*) real, (*b*) virtual.

CHAPTER VIII

THE REFRACTION OF LIGHT

LET us now make experiments which will help us to understand why a lens causes the bending of light falling on it.

(*a*) Place a glass block over a straight line on a sheet of paper. Draw what you see from various positions. One view is shown in fig. 86.

(*b*) Draw the appearance of a stick in a tank of water (fig. 87).

(*c*) Notice the appearance of the bottom of a clear pool of still water as you approach it from a distance. Verify that when viewed obliquely from a distance it appears much shallower than when viewed from above.

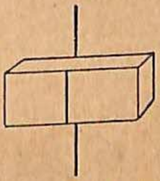
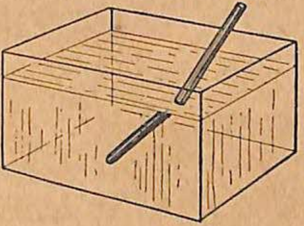


FIG. 86.—A line viewed obliquely through a glass block



Appearance of a stick in water

FIG. 87.

(*d*) Place a coin at the bottom of a basin. Stand so that the rim just hides the coin from your eye. Pour water into the basin, keeping your eye in this position. Describe what you observe.

Common examples such as you have just observed suggest that light gets bent when it passes from one medium to another. Take a rectangular block of glass, one side of which has been ground by rubbing it on emery paper moistened with a 10 per cent. solution of camphor in turpentine. Place this with the rough side on a sheet of paper and on to it direct a ray of light from the optical apparatus already described. The path of the bent or *refracted* light will be seen in the glass. Mark the track with pins ABCD as shown in fig. 88. Is all the light refracted? Draw a line round the block. Remove the block and join up the pins so as to have a record of what is observed. Notice that on entering the glass the ray is bent *towards* the normal, on emerging it is bent *away* from the normal. If the opposite sides of the block are parallel, the emergent ray is parallel to the incident ray.

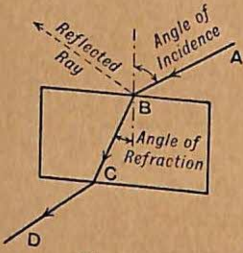


Fig. 88.

Replace the block and pins ABCD after removing the light. Place your eye level with the paper. Note that pins A and B when viewed through the glass appear in line with CD. This suggests an accurate method of tracing rays through glass, using pins instead of light rays.

Measure and tabulate the angles of incidence and refraction for several incident rays at different angles to the normal.

Angles of	
Incidence	Refraction
0	
10	
20	
30	
40	
50	
60	

Can you detect any relation between these angles?

Early attempts were made to discover a simple relation between the angles of incidence and refraction by the Greeks. No relation was found until in 1621 a Dutchman named Snell discovered that, although there is no relation between the angles, refraction obeys a simple law. This we shall now show.

Using the traces you have made, draw a normal from any

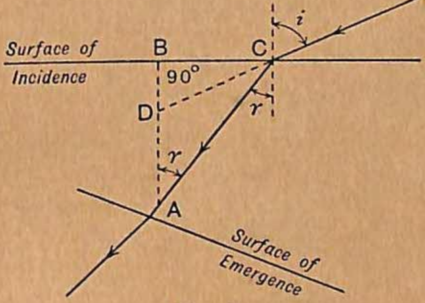


FIG. 89.

point A on a refracted ray (fig. 89). *This normal must be drawn to the surface BC at which the light enters the glass.*

Produce the incident ray to meet the normal in D. Measure CA and CD and find their ratio. Repeat for each trace.

Results :—

CA	CD	Ratio $\frac{CA}{CD}$
cm.	cm.	

The experiment should be repeated for different shapes of glass, and results of the class should be compared.

It is always found that the ratio $\frac{CA}{CD}$ is approximately constant for the same block of glass.

Students who know a little trigonometry will easily verify with the help of fig. 89 that

$$\frac{CA}{CD}=\frac{\frac{CB}{CD}}{\frac{CB}{CA}}=\frac{\sin i}{\sin r}$$

and thus

$$\frac{\sin i}{\sin r}=\text{constant.}$$

This ratio $\frac{\sin i}{\sin r}$ or $\frac{CA}{CD}$ is called the *refractive index from air to glass.* It is usually denoted by the Greek letter *mu*, which is written μ.

Thus μ_{ag} or ${}_a\mu_g$ means the refractive index of light in passing from air to glass; μ_{ga} or ${}_g\mu_a$ means the refractive index in passing from glass into air.

From fig. 90 ${}_g\mu_a=\frac{CD}{CA}$ and this is less than 1.

In fact, ${}_g\mu_a=\frac{1}{{}_a\mu_g}$.

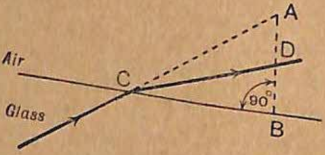
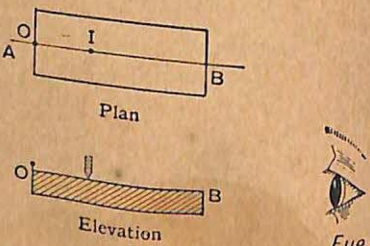


Fig. 90.



Plan

Elevation

Fig. 91.

Position of an Image in a Block of Glass

Place the rectangular block of glass so that the ground face is on top and one pair of parallel sides is at right angles to a line AB (fig. 91).

Fix a pin O on AB, touching the glass as shown. Observe this pin along the line AB through the glass and move a pencil, I, point downwards on the top of the glass until there is no parallax between I and O for *small* movements of the eye from side to side. The pencil point will then coincide with the image of O, and its position may be fixed by marking the glass.

Measure the thickness OB of the glass and the distance BI to the image from B. Obtain the ratio $\frac{\text{BO}}{\text{BI}}$. This is the ratio of the $\frac{\text{real depth}}{\text{apparent depth}}$ of pin O seen through the glass. Repeat the experiment, looking through the other edges of the glass.

The ratio is the refractive index, as will be clear in referring back to fig. 89. For $\mu = \frac{\text{CA}}{\text{CD}}$, and when C is close to B as in your experiment,

$$\frac{\text{CA}}{\text{CD}} = \frac{\text{BA}}{\text{BD}} = \frac{\text{real depth}}{\text{apparent depth}} \text{ very approximately.}$$

The Meaning of Refractive Index—Imagine that a company of soldiers AB marching over smooth ground suddenly reaches a patch of ploughed land at XY (fig. 92 (*a*)), but still goes marching on. The line will travel only a distance XA′ in the time it took to travel AX on the smooth land. If the line of soldiers meets the boundary XY obliquely as in fig. 92 (*b*), the end Y will be slowed up more than end A, with the result that when all the line is on the rough ground it will be parallel to XB′, and the new direction will be YB′. Here again AX is the distance travelled on smooth ground in the time taken to travel YB′ on rough ground.

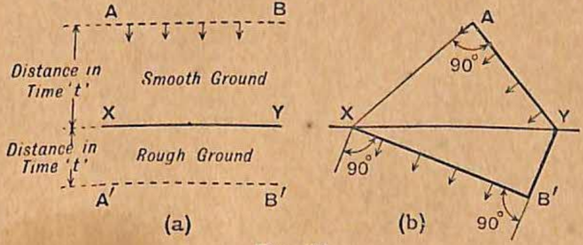


FIG. 92.

Thus $$\frac{AX}{YB'} = \frac{\text{speed on smooth ground}}{\text{speed on rough ground}}.$$

It is now known that the refraction of light occurs from a similar cause—the light travels in different media at different speeds, and the refractive index gives the ratio of its speeds in the two media.

Thus $${}_a\mu_g = \frac{\text{speed of light in air}}{\text{speed of light in glass}}$$

$${}_g\mu_a = \frac{\text{speed of light in glass}}{\text{speed of light in air}}.$$

Other Suggested Exercises

Find the refractive index of water and other clear liquids, using a thin medicine bottle containing the liquid and lying on its side. The refraction of the glass can be neglected if the glass is thin in comparison with the width of the bottle.

Further Study of Refraction

Consider a series of rays AO, BO, . . . etc., incident at O on a glass surface (fig. 93). The refracted rays OA′, OB′, . . . etc., are bent towards the normal. A ray, DO, incident at nearly 90°, is refracted along OD′. The angle of refraction is then the *greatest which is possible*, and is called the *critical angle*. Imagine the same rays reversed so that they are travelling from glass to air. The last to emerge must be D′O. **The critical angle is thus the greatest angle of incidence in the denser medium for the light to emerge into the rarer medium.**

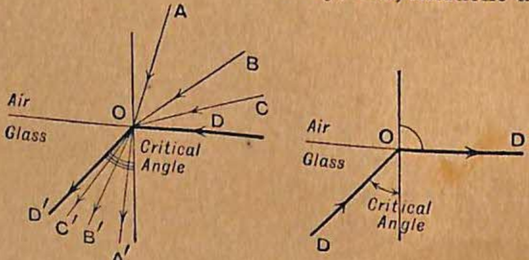


FIG. 93.

What happens if the light is incident in glass at an angle greater than the critical angle?

The *critical angle for glass* is about 41°–43°. It varies with the composition of the glass and is always *less than* 45°. Thus **total reflection** will occur in glass when the angle of incidence in glass is 45°. This fact is made use of in *totally reflecting prisms* (fig. 94). These are made of glass, and their angles are 45°, 90°, 45°.

Set up prisms as shown in fig. 94:

(*a*) Turning a ray through 90°.

(*b*) Two prisms, each turning a ray through 180°.

(*a*) is used in periscopes; (*b*) is used in prismatic binoculars.

Explain carefully why it is possible for the prisms to behave in this way.

Prisms for use in this way are expensive, for their faces and angles must be very true. At first sight it may appear that plane mirrors would do the work equally well and at much less cost. In practice it is found that totally reflecting prisms are immensely superior to silvered mirrors, because the latter reflect much less light than the former. It is true that the glass of the prism absorbs a little light, but much less than is lost at a mirror.

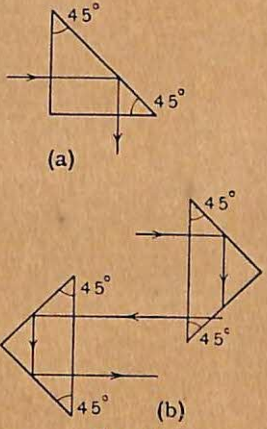


FIG. 94.

What a Fish may see

Fig. 95 shows how a fish sees an angler sitting on the bank so that his head appears to be along line OA. No wonder the fish is easily frightened when the angler appears. The fish sees the whole horizon outside the water within the shaded cone shown in fig. 95. It also sees the bottom of the pond both directly and by total reflection. The refractive index for water is 1·33 or $\frac{4}{3}$. Find, by an accurate drawing, the size of the angle of the double cone shown in fig. 95. (Answer $2 \times 49 = 98°$.)

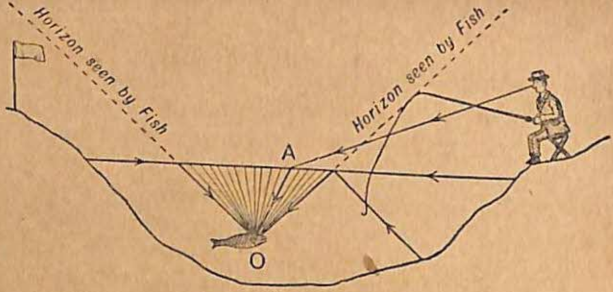


FIG. 95.

Lenses

Lenses may be considered as being made up of large numbers of prisms with the corners rounded off as in fig. 96.

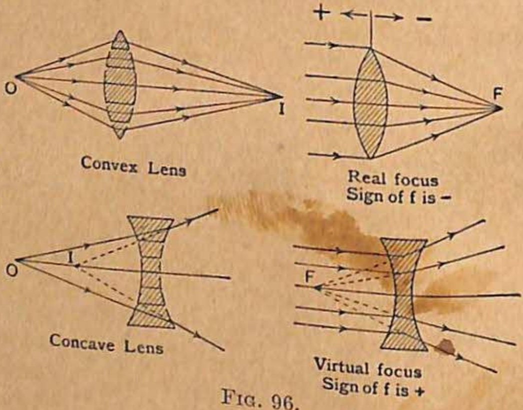


FIG. 96.

All rays starting from a point O, after refraction in the lens, pass through, or appear to diverge from, a point I which is called the image of point O.

Other Examples of Refraction

Atmospheric Refraction

The atmosphere normally grows denser nearer the earth. This causes rays from the sun and stars to become bent as they pass obliquely through the atmosphere. Thus we may see the sun when it is really below the horizon. This is illustrated in fig. 97, which shows how an observer at A sees the sun in the direction AB when it has really set.

You have probably observed that when near the horizon the sun often appears oval-shaped. This is because rays from the lower edge have to pass through a greater thickness of air than rays from the upper edge, and in consequence they are refracted more. Thus the vertical diameter appears to be decreased, whilst the horizontal diameter is unaltered.

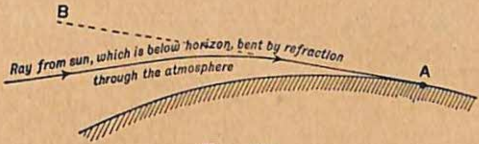

B
Ray from sun, which is below horizon, bent by refraction through the atmosphere
A

FIG. 97.

The Mirage—This phenomenon is an interesting example of total reflection. On a hot day pools of water appear to be lying along a level tarred road, and approaching traffic is reflected from them as though in a mirror. This is particularly noticeable when the eye is only a foot or two above the road. Thirsty travellers in the desert are often misled by the appearance of a lake of water. The cause of this will be understood from fig. 98.

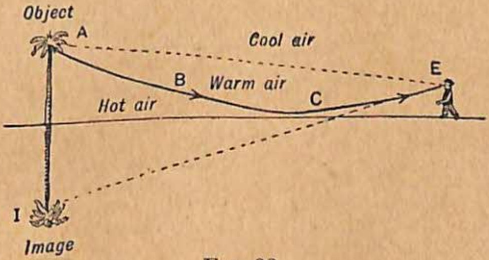


FIG. 98.

The ground being very hot, heats the air in contact, which then becomes more rarefied near the earth than up above. The ray of light AB is then refracted more and more as it passes gradually into the rarefied layers and may become totally reflected at C, entering the eye of the traveller from the direction IE. The traveller also sees A directly along EA. Rays from the sky to right and left of A are also totally reflected, so that the palm-tree looks as if it is on the bank of a pool of water.

A mirage may be obtained in the laboratory by spreading a thin level layer of sand on a sheet of asbestos or sheet-iron

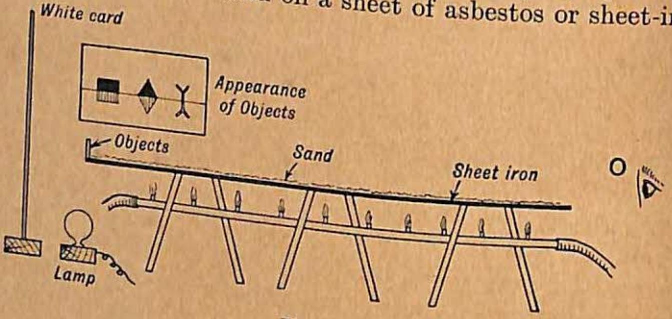


Fig. 99.

heated by a long gas-pipe with several holes at which the gas burns. A lamp underneath illuminates a white screen, and small black cardboard figures about a cm. or so high are put on the sand near the screen. The fig. 99 shows the arrangement and the appearance of the objects.

QUESTIONS

1. Draw a diagram showing a ray of light passing from air into a rectangular block of glass and out again. Mark in the angles of incidence and refraction at the first face of the block.
2. What is meant by refractive index? Illustrate by the help of a diagram.
3. Draw a diagram and explain how a ray of light from the sun may reach the eye after the sun has really "set."
4. What is meant by total reflection? Illustrate by reference to diagrams.
5. Show how total reflection may be used in glass prisms.
6. Describe a mirage and explain the phenomenon.

CHAPTER IX

OPTICAL INSTRUMENTS: MICROSCOPES, TELESCOPES, THE CAMERA, THE EYE

Combinations of lenses are used in optical instruments, the more familiar of which will now be described.

The Simple Magnifying Glass or Reading Glass

You have learnt that a convex lens gives a magnified image of an object placed inside the focus. Fig. 100 shows how the image is formed, and fig. 101 shows the eye looking at such an image.

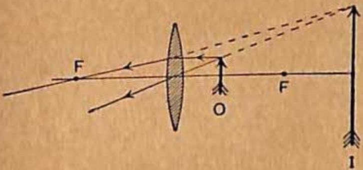


Fig. 100.

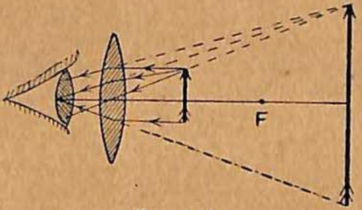


Fig. 101.

The Astronomical Telescope

Obtain two convex lenses of about 15 to 30 cm. and 2 or 3 cm. focal length. Prepare two cardboard tubes which slide into each other and which will give a total length just over the sum of the focal lengths of the lenses you have selected. The wider tube should be a little wider than the diameter of the larger lens. Near one end of this tube fix four small screws for the lens to rest against, and fasten it in with the help of rubber bands.

Cut a piece of cardboard to fit the smaller tube (fig. 102). Cut out a hole centrally for the small lens, and fasten this in with the help of sealing-wax. In the same way fix the cardboard on to the end of the tube. You have made an astronomical telescope, and by sliding the tubes you can focus it on a distant object. The image is inverted, but this is no drawback when observing the stars.

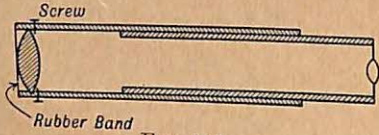
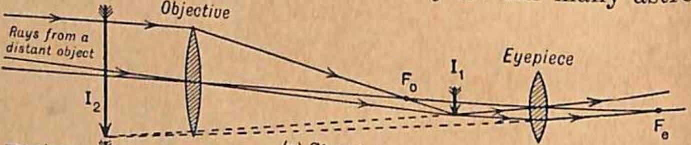
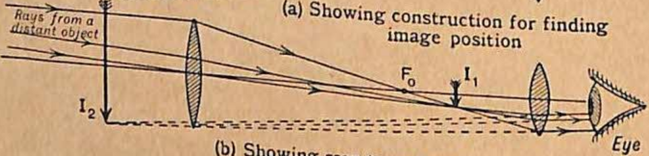


FIG. 102.



(a) Showing construction for finding image position



(b) Showing rays traced right through the system

FIG. 103.

Rays from a distant object form an image I_1 just outside or at the focus of the objective (fig. 103). The eyepiece, acting like a simple magnifying glass, forms a virtual and magnified image I_2 or I_1. As the image is inverted, this form of telescope is of no use for terrestrial work, but by its aid many astronomical discoveries have been made. In practice, when observing a star, the instrument is racked out so that the image I_2 is at infinity. The two lenses are then separated by a distance equal to the sum of their focal lengths. The object and image being each of indeterminate size and distance, the magnification cannot be expressed as

$$\frac{\text{size of image}}{\text{size of object}},$$

but is defined as the ratio of the

$$\frac{\text{angular dimensions of the image}}{\text{angular dimensions of the object}}$$

at the eye.

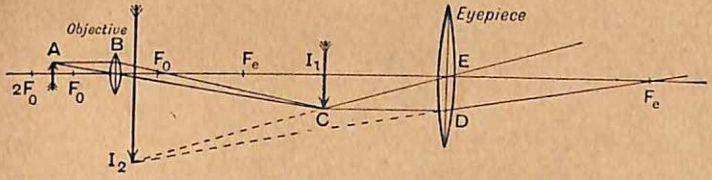
The magnification of an astronomical telescope may be shown to be equal to the ratio

$$\frac{\text{focal length of the objective}}{\text{focal length of the eyepiece}},$$

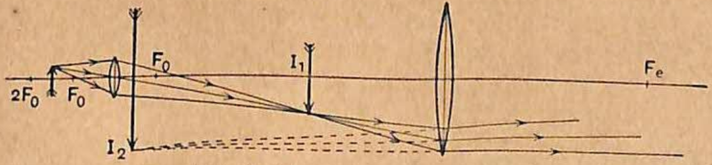
and the separation of the lenses when viewing a distant object is the sum of these focal lengths. Thus an objective of 10 in. focal length and an eyepiece of 1 in. focal length may be made into a telescope when mounted in a cardboard tube 11 in. long, and the magnification will be 10.

The Compound Microscope (fig. 104)

In this instrument two convex lenses are used. The object is placed just outside the focus of the objective, which forms a real, inverted, magnified image at I_1, which is arranged to fall inside the focus of the eyepiece. This then acts as a simple magnifying glass, and the eye placed close to the eyepiece sees at I_2 a virtual magnified image of I_1. The objective and eyepiece are at a fixed distance from one another, and by focussing, the image I_2 is arranged to be at the near point



(*a*) Showing how image position is found. AB and CD are parallel to the axis. AC and CE pass through the centres of the lenses.



(*b*) Showing rays traced right through the system from the tip A of the object.

FIG. 104.

of the eye. For a normal eye this is 25 cm. The image is inverted.

The Enlarging (or Magic) Lantern (fig. 105)

A condensing lens C is placed so as to make the light from a lamp S converge so as to fill the aperture of the focussing lens L, so illuminating the slide O uniformly. The slide is at a distance between F and 2F away from a lens L, which then casts a magnified real image on the screen. To obtain an upright picture the slide is inverted.

Focussing is easily done by means of a screw which alters the distance between lens L and the slide O.

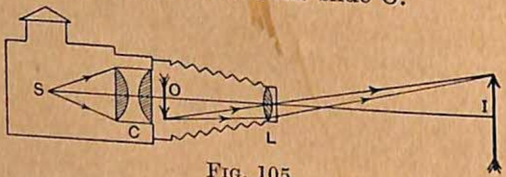


Fig. 105.

The cinematograph is a "magic" lantern in which the object is changed 15 or 20 times a second by means of machinery. The image received by the eye persists for a fraction of a second, and so the various images merge into each other giving the impression that movement is taking place.

The Camera

This consists of a dark box containing a lens, a shutter provided with "stops" to regulate the amount of light entering the lens, and a sensitive plate or film.

In the "fixed focus" type the lens is fixed so that the plate or film is in the focal plane, and then all objects at a greater distance than, say, 30 ft. are in focus.

If it is desired to focus on nearer objects, arrangements must be made for increasing the distance between lens and plate. Usually a scale fastened to the base of the camera gives the setting positions so that images of objects at various distances shall be in focus on the plate.

The Optical System of the Eye

The human eye resembles the camera in most respects. The thickness of the *lens* L may be altered by means of the *ciliary* *muscle*, and thus the focal length may be varied. A screen, the *retina*, receives the images formed by the lens. The *aqueous humour* A and the *vitreous humour* V are fluids which, together with the lens L, really make a combination of lenses. In front of the lens is the *pupil*, which admits the light and is automatically adjusted in size by a diaphragm called the *iris*, so that the eye does not receive more light than it can endure. The whole is enclosed in a thick horny coating, the *sclerotic*, which, in front of the lens, is transparent and called the *cornea*. The retina consists of the sensitive ends of the fibres of the optic nerve, which enters the eye at some distance from the optic axis. This part of the retina, known as the *blind spot*, is insensitive to light.[1]

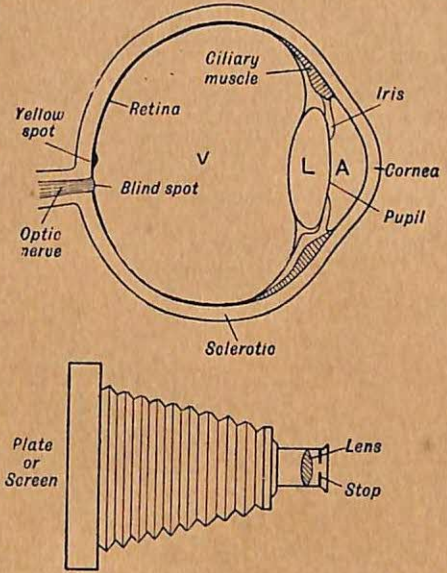


FIG. 106.

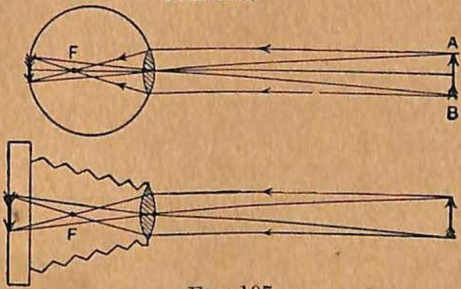


FIG. 107.

The diagrams (figs. 106 and 107) show how the eye and the camera form *inverted* real images of objects. That we see objects the right way up is because of the way the brain *interprets* these images. Focussing, in the case of the camera, is done by altering the distance of the lens from the screen;[2]

---

[1] Compare pages 202 and 203.

[2] This is the case with the frog, see p. 202.

in the case of the eye this distance is fixed, so the ciliary muscle alters the focal length of the lens. This alteration of focal length to suit vision when the object distance varies is called *accommodation*. The average or normal eye, when at rest, is focussed for infinity, which is the *far point* of the normal eye. The *near point* of a normal eye, at which reading may be comfortable, is 10 in. or 25 cm.

Defects of Vision

The commonest are

- (*a*) Loss of accommodative power.
- (*b*) Short sight (Myopia).
- (*c*) Long sight (Hypermetropia).
- (*d*) Astigmatism.

(*a*) occurs mainly in old people who lose the ability to alter the thickness of the lens. Such persons require two spectacles, one for viewing distant objects and the other for reading. Nowadays these may be combined in one pair of glasses, the upper part A providing for distant vision and the lower part B for near vision (fig. 108).

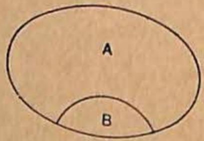


Fig. 108.

(*b*) *Short-sighted people* have too long an eyeball and can see near objects clearly, but the ciliary muscle cannot make the lens thin enough for it to focus images of distant objects on the retina. When the eye is at rest these images are brought to a focus in *front* of the retina. Such persons require concave spectacles to enable them to see distant objects.

The defect and its cure may be illustrated by means of an experiment described in Bragg's *Universe of Light*. A flask contains water to which a little fluorescin has been added. Parallel rays from an optical box fall on a convex lens of suitable focal length and may be traced inside the flask by means of the fluorescin (fig. 109 *a*). A suitable concave lens placed in front of the flask causes the rays to be focussed on the “ retina ” (fig. 109 *b*).

(*c*) *Long-sighted people* have too short an eyeball. The eye can be accommodated to view distant objects but not near objects. When the eye is at rest rays from distant objects are brought to a focus *behind* the retina. The defect and its cure may be illustrated by experiment as shown in fig. 110. The additional convex lens increases the accommodative power so that rays from near objects can be focussed.

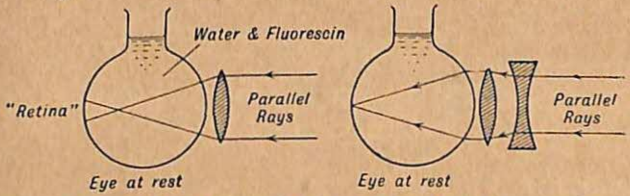


FIG. 109.—(*a*) Illustrating short sight, and (*b*) its correction

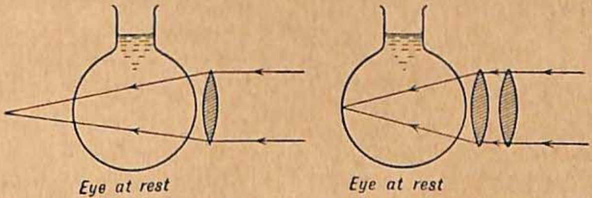


FIG. 110.—(*a*) Illustrating long sight, and (*b*) its correction

(*d*) *Astigmatism* is due to the lens of the eye having different curvatures in different directions. It is corrected by means of a suitable cylindrical lens.

QUESTIONS

1. Describe the optical system of a reading glass.
2. Explain with the help of a diagram how a compound microscope works.
3. Describe an astronomical telescope and explain how it works.
4. Show by the help of a diagram how a magic lantern works.
5. Compare the human eye with a camera, pointing out any similarities and differences.
6. What is meant by (*a*) short sight, (*b*) long sight? How is each corrected? Illustrate your answer by means of diagrams.

CHAPTER X

EXPERIMENTS WITH TRIANGULAR GLASS PRISMS. COLOUR. SPECTRA

Experiment 1

When the sun is shining into the laboratory hold a triangular glass prism in the path of the rays. By turning it round you should be able to get a brilliant patch of various colours on the wall or the floor (fig. 111).

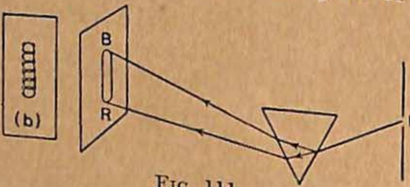


FIG. 111.

Fix the prism in a clamp which can be turned in a retort stand and notice what happens as the prism is rotated. The patch of colour is called a *spectrum*, and you will find it is clearest when the deviation is least. If the laboratory can be darkened and the sunlight admitted through a small hole about $\frac{1}{4}$ in. in diameter in the blind, you will find that the extreme edges of the spectrum are curved. This experiment was first described by the great Isaac Newton. In his own words, "I turned the prism slowly and saw the refracted light on the wall, or coloured image of the sun *first to descend* and

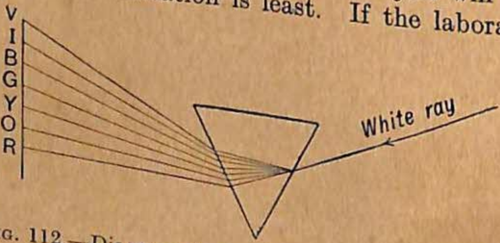


FIG. 112.—Diagram showing how a single white ray is decomposed by a prism

then to ascend. . . . When the image seemed stationary I stopped the prism and fixed it in that posture. . . . In that posture the refraction of the light at the two sides of the refracting angle, *i.e.* at the entrance of the rays into the prism and at their going out of it, were equal to one another."

Newton noticed that the ends of his spectrum were curved, and he concluded that he was observing a series of overlapping coloured images of the sun, showing these by the sketch (fig. 111 (*b*)). He gave the order of the colours as red, orange, yellow, green, blue, indigo, violet (fig. 112).

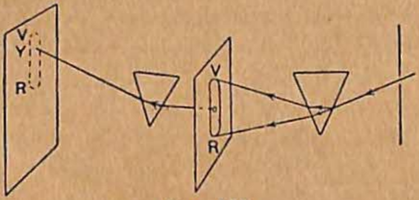


FIG. 113.

Experiment 2

Allow the spectrum to fall on a card with a small hole in it as in fig. 113 and insert a second prism as shown, between the card and a screen. Move the card so that the hole passes gradually from V to R. Note that there is no further splitting-up of the light. In this way Newton satisfied himself that the various colours were not further decomposed by a second prism.

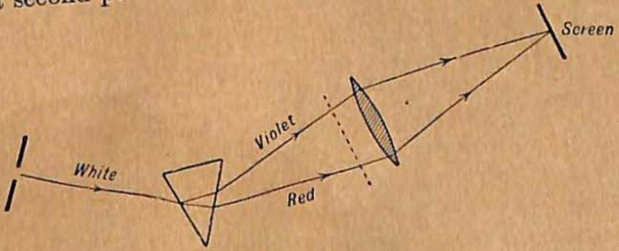


FIG. 114.

Experiment 3

Insert a large convex lens between the prism and the screen, so that it catches the whole spectrum (fig. 114).

Move the screen until all the rays are brought to a focus. The result is white light.

The experiments suggest that white light is really a mixture of various colours which is split up by the prism into its various components. The lens causes these to recombine and form white light.

Experiment 4

Now insert pieces of cardboard of various thicknesses in the position of the dotted line in fig. 114 (above) so that one colour at a time is cut off from the lens. Make a list showing the colour of the image on the screen in each case. You are observing what are known as *complementary* colours. For instance, *white light minus red* appears *green*. This particular green is called *minus red* and is not a pure colour as it may be split up by a prism into the colours of the spectrum with red missing. Arrange your result thus :

Colour of spectrum	Complementary colour (white *minus* the spectrum colour)
Red	Green
Orange	
Yellow	
Green	
Blue	
Indigo	
Violet	

Experiment 5—To obtain a Pure Spectrum on a Screen

It is usually more convenient to obtain a spectrum by means of artificial light. This may be done in the following manner. The straight thin filament of an automobile lamp makes an ideal source, and four sets may use the same lamp if it is fixed in the centre of a square bench.[1]

By means of a lens L focus an image of the filament on screen S. Then insert the prism and move the screen to one side and also the prism until the spectrum is clearest (fig. 115). A piece of cardboard may be placed so as to cut off the direct light. The spectrum is said to be pure because all the rays of a particular colour are brought to a focus at one place.

---

[1] Or the ray-box may be used.

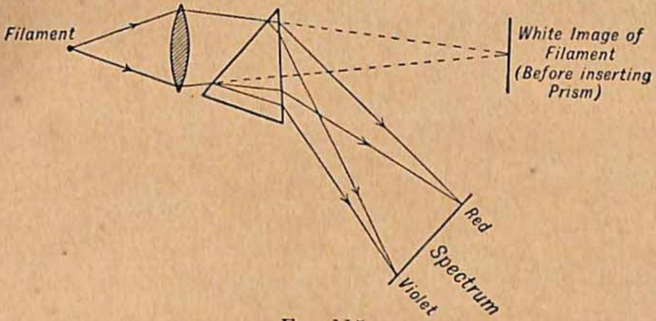


FIG. 115.

Experiment 6

You should obtain a series of coloured gelatine films—the Wratten filters supplied by Kodak are excellent and include pure red, blue, and green, and also complementary filters.[1]

Place in the path of the light

(*a*) A pure red filter.
(*b*) A pure blue filter.
(*c*) Both the above.

Does the filter turn the whole spectrum into one colour? If not, describe what it does in each case. Try to explain (*c*).

Now insert other filters in the path of the light and describe what you observe in each case.

How do you account for the colour of a colour filter?

---

[1] The Strand Electric Co., 19–24 Floral Street, W.C.2, supply large sheets 22 × 17½ in. at 8d. each. The most useful are:—

Red	No. 14
Green	,, 24
Blue	,, 20
Yellow	,, 1
Magenta	,, 12
Peacock blue	,, 15
Purple	,, 25

(See *The Science Masters Book*, vol. i, p. 71—a most interesting series of experiments on colour is therein described by E. G. Savage.)

Experiment 7

Insert across the spectrum in turn a series of coloured wools, red, green, yellow, blue, etc. In each case state what you observe, and particularly note any pure colours. What is the appearance of a pure red wool

(*a*) In the red light of the spectrum?
(*b*) In the green light of the spectrum?
(*c*) In the blue light of the spectrum?

How do you account for the colours of the fabrics?

Experiment 8—Pigments

You are aware that painters obtain green by mixing blue and yellow pigments. If these colours are *pure* they should give *black* when mixed. Since green results, we are driven to the conclusion that the colours are not pure but that *green* is common to both. Verify this by placing each pigment in turn in the spectrum of white light.

Experiment 9

In a darkened room make a sodium flame by burning a pencil of fused sodium chloride[1] in a Bunsen flame. This gives an intense yellow light which is practically pure. Examine the appearance of various coloured wools, coloured railway posters, and crinkled paper in this light. Note especially the appearance of a person's face and lips. Account for what you observe.

Experiment 10

You should examine the spectrum of the lamp filament as this is gradually made hotter by cutting out a resistance inserted in the circuit. The observation is made by looking through a prism, the refracting edge of which is parallel to the filament. Note how, as the wire begins to glow, first red appears and then the other spectrum colours are added in turn until when the filament is white-hot a full **continuous spectrum** is seen. *All incandescent solids give continuous spectra.*

---

[1] Obtainable from British Drug Houses: 5s. 6d. a dozen.

The Spectra of Glowing Gases

If a discharge from an induction coil is passed through a tube containing the gas at low pressure the gas glows. Tubes for this purpose are usually of the shape shown in fig. 116, and the narrow part of the tube emits an intense light when excited as described. Observe the spectra of various gases by looking through a prism with its refracting edge parallel to the tube. Note that the *spectrum of gas consists of a series of bright lines.* Each has its own particular spectrum, and from the position of the lines the gas may be identified. It is usual to view the spectra of vapours and gases through some kind of **spectroscope,** which instrument incorporates a narrow slit, lenses, and prisms so arranged that the observer views a magnified spectrum through the eyepiece. If you view a sodium flame through such an instrument you will observe simply two fine yellow lines very close together. Thus, such a flame is a very near approach to light of one colour, or monochromatic light.

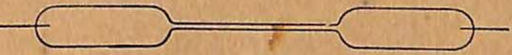


FIG. 116.—Spectrum tube for gases

The Solar Spectrum

On observing the spectrum of sunlight through a spectroscope you will observe a continuous spectrum crossed by a series of dark lines. These are called Fraunhofer lines, after the man who first studied them. In the yellow you will find the two lines characteristic of sodium but *black* instead of yellow. The other dark lines, of which there are several hundred, are all found in the same place as the bright lines of the emission spectra of certain elements, and for a long time the reason for their being dark was a puzzle to scientists. In 1861 Bunsen and Kirchoff solved the puzzle and showed that the dark lines are due to the absorption of some of the light from the intensely hot interior of the sun, by cooler gases and vapours in its atmosphere. Thus from the study of the spectrum of the sun and the stars scientists have discovered some of the materials of which they are composed. In all cases it is found that the stellar materials are of the same nature as the materials which compose the earth.

Why is a Prism enabled to split up White Light?

You will remember that to explain the refraction of light we decided that the speed of light is greater in air than in glass. Since red light is refracted less by a prism than green or violet light we conclude that red light travels faster through glass than does green or violet light.

You should draw a narrow red and a violet line side by side on a piece of paper and paste them on to a black background.

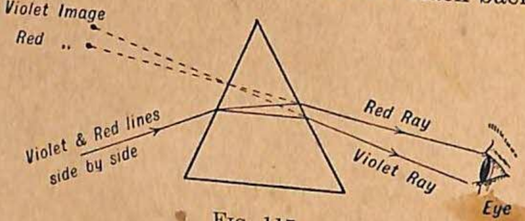


FIG. 117.

Look at them through a prism with the refracting edge parallel to the lines. You will see the violet *image* above the red image. Thus violet has been deviated more than red, and so the violet *ray* emerges *below* the red ray. This is shown in fig. 117.

This experiment was first described by Isaac Newton, who made the first exhaustive study of the spectrum and was the first man to learn the truth about colour.

Further fascinating experiments in colour are described in *The Science Masters Book.*

QUESTIONS

1. Draw a diagram showing how a single white ray falling on a prism is split up into coloured rays.
2. Describe a method of combining the coloured rays of question 1 to re-form white light. Illustrate by drawings.
3. Show, with the help of a drawing, how you could obtain on a screen a pure spectrum of white light.

4. Explain the action of (*a*) a pure blue colour filter, (*b*) a pure red wool, when white light falls on them. How could you verify your explanations by experiments?

5. What will be the appearance in sodium light of coloured wools which in white light appear (*a*) red, (*b*) yellow, (*c*) blue, (*d*) green? Give reasons.

6. Distinguish between a continuous spectrum and a bright line emission spectrum. Which of these is characteristic of the substance emitting the light?

CHAPTER XI

THE LAW OF CONSERVATION OF MASS AND THE LAW OF CONSTANT PROPORTIONS

BEFORE one can get a clear understanding of the reactions which occur between chemical compounds, and before the amounts of substances which react together can be determined, it is necessary to consider fundamental laws which govern such reactions.

A **law** in science is simply a general statement which sums up a number of isolated facts. These laws form the basis of scientific theory; in fact, a **theory** may be said to be an attempt to make laws understandable to our minds—to give them *point*.

The Law of Conservation of Mass or the Law of Indestructibility of Matter

In order to show that there is no loss in weight during a chemical reaction, it is essential that the experiment is conducted in a closed vessel so that there can be no escape of any of the materials used or formed.

The divided flask (fig. 118) is used for this experiment. By means of a pipette run a solution of Sodium Chloride into one compartment and a solution of Silver Nitrate into the other. Cork the flask and weigh it. Tilt the flask so that the solutions mix. A white precipitate of Silver Chloride is formed. Weigh again.

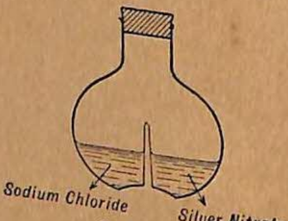


FIG. 118.

(*Note*—A variety of solutions may be used and the results compared. Ferric Chloride and Sodium Hydroxide; Nickel Sulphate and Ammonium Sulphide; Copper Sulphate and Sodium Carbonate are quite suitable.)

The results of the above experiment in which many substances have been used can be summarised in a general statement as follows :—

There is no change in total weight when a chemical reaction occurs, or **The total weight of the reacting substances is the same as that of the products formed.**

This law was first stated by Lavoisier in 1774. The experiment which he used may be repeated quite easily in the laboratory. A weighed quantity of tin was enclosed in a sealed vessel full of air. The vessel and its contents were weighed. The vessel was then heated, and the tin changed colour and a white powdery oxide of tin was formed. The tin had combined with some of the oxygen of the air. After cooling, the vessel and its contents were found to weigh the same as before. By means of further experiments Lavoisier went on to show that the tin had gained just as much weight as the air had lost.

Chemical Compounds are Constant in Composition

This fact was referred to when compounds were first discussed (Part II, p. 10).

The French chemist Proust in 1799, after analysing a large number of compounds, both those occurring in Nature as minerals and those prepared in the laboratory, made the following general statement which is called the **Law of Constant Proportions:**[1] **A chemical compound, no matter how it is prepared, always contains the same elements combined together in fixed proportions by weight.**

A great controversy took place between Proust and another French chemist Berthollet (1748–1822). The latter chemist thought that the composition of a chemical compound could vary. Most of the examples which Berthollet cited were shown by Proust to be mixtures in varying proportions of two or more compounds. The controversy occupied about five years (1803–8), but at the end of that time Proust had definitely established the law of constant proportions.

The difficulty you will experience in verifying the law in the laboratory is the preparation of the pure specimen, the composition of which you are going to determine.

---

[1] It is also called the law of constant composition and the law of definite proportions.

An interesting and reasonably simple compound which you can prepare is Cupric Oxide. It can be prepared in several ways and then each sample can be analysed. It will save time if various sections of the class make themselves responsible for different parts of the experiment, always remembering that a mistake made by any one section will spoil the result.

Section (i)—Preparation of Cupric Oxide from Copper, using Nitric Acid

Put about a square inch of pure copper foil into an evaporating basin. Cover with Nitric Acid (50 per cent. pure acid+50 per cent. water) and heat in a fume cupboard, adding more acid if required *until all the copper has disappeared.* Evaporate to dryness and finally heat very strongly until all is converted into Cupric Oxide and no more fumes are evolved.[1] Collect all the samples made in this way in a crucible and keep them in a desiccator until required by Section (iv). The chemical changes may be expressed as follows :—

$$\text{Copper} \xrightarrow{\text{Nitric Acid}} \text{Copper Nitrate} \xrightarrow{\text{heat}} \text{Cupric Oxide.}$$

Section (ii)—Preparation of Cupric Oxide from Copper Sulphate

To a solution of Copper Sulphate in a beaker add a solution of Sodium Hydroxide in slight excess (*i.e.* until the solution is slightly alkaline). Boil until the precipitate is quite black and then filter. **Wash the residue thoroughly with hot distilled water until the water dripping from the funnel no longer turns litmus blue.** This is most important if a good result is to be obtained. The whole of this section of the class should use one fairly large funnel for filtering, so that all the residue is collected on one filter paper. Dry the residue in a steam oven. If no steam oven is available, use an arrangement shown in fig. 119; it has been found quite effective by the authors. When dry, the Cupric Oxide is collected in a crucible and placed in the desiccator until required by Section (iv).

---

[1] See p. 112.

The chemical changes may be expressed as follows :—

$$\text{Copper Sulphate} \xrightarrow{\text{Sodium Hydroxide}} \underset{\text{(blue precipitate)}}{\text{Cupric Hydroxide}} \xrightarrow{\text{heat}} \text{Cupric Oxide.}$$

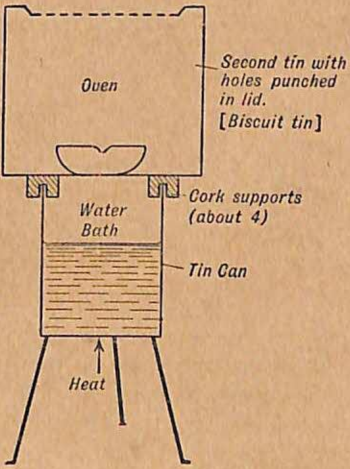


Fig. 119.

Section (iii)—Cupric Oxide from Copper Carbonate

Heat a sample of *pure* Copper Carbonate in a crucible *until there is no further loss in weight.* The resulting black powder is Cupric Oxide.

$$\text{Copper Carbonate} \xrightarrow{\text{heat}} \text{Cupric Oxide} + \text{Carbon Dioxide} \uparrow .$$

Section (iv) [1]

While Sections (i), (ii), and (iii) are preparing samples of Cupric Oxide, the fourth section should fit up the apparatus shown in fig. 120.

Three porcelain boats are heated to drive off any moisture which may be collected on the surface of the porcelain, and then cooled in a desiccator. They are then weighed. The Cupric Oxide prepared in the three different ways is introduced into the respective boats, and the boats reweighed. It is wise not to fill the boats quite to the top and to wipe the outside very carefully before weighing. The boats are now put into the furnace tube and pushed into position by a glass rod or stout wire. (Take care that the porcelain loops on the boats all point one way—it is then easier to get them out.)

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[1] It may be most convenient for this section to be done as a demonstration.

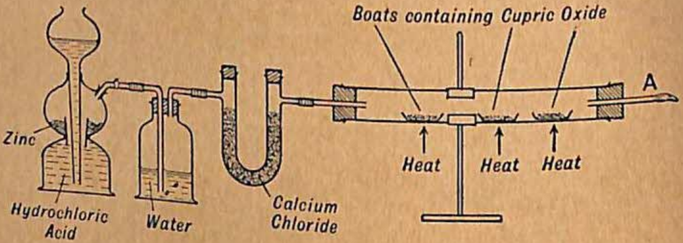

Fig. 120.

The Bunsen burners are *not yet lighted.* Hydrogen in a *very slow stream* is passed through water and then Calcium Chloride, and finally over the surface of the boats. *If the stream of Hydrogen is rapid what will happen to the powdered Cupric Oxide in the boats?* The Hydrogen is collected in a test tube (fig. 120A) and tested until a **very feeble** explosion occurs. **It is then safe to light the gas under the furnace tube.** After heating strongly for about ten minutes the Bunsen burners are shut off and the tube allowed to cool, Hydrogen being passed through all the time.

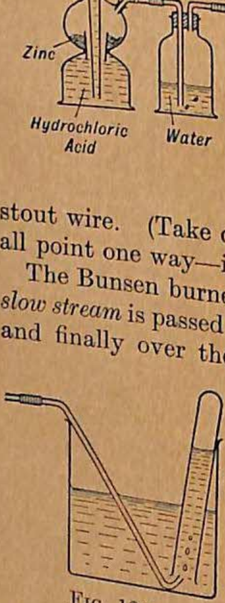

Fig. 120A.

When cool, the Hydrogen supply is shut off and the boats + copper are weighed, and then the boats are replaced in the furnace tube for a further heating. (It is necessary to test the Hydrogen again before lighting the gas burners.)

If on weighing a second time there is no further loss in weight the experiment is completed. If there is any loss in weight the boats must be re-heated and weighed **until the weight is constant.** This is the only method of knowing whether or not the heating has been continued long enough.

Hydrogen is used in is experiment as a **reducing agent**. It removes the oxygen f n the Cupric Oxide, combining with it to form water.

The following results were obtained by a class of pupils performing this experiment in the manner described above :—

	1st sample	2nd sample	3rd sample
	grm.	grm.	grm.
Weight of boat	5·14	4·82	5·16
,, ,, + Cupric Oxide .	5·69	5·28	5·67
,, ,, + Copper (i) .	5·57	5·20	5·59
,, ,, + Copper (ii) .	5·57	5·18	5·56
,, ,, + Copper (iii) .	. .	5·18	5·56
Weight of Cupric Oxide used .	0·55	0·46	0·51
,, ,, Copper left . .	0·43	0·36	0·40
∴ per cent. of Copper in Cupric Oxide	78·2	78·2	78·4

This experiment has been described in detail to show the care necessary to verify a chemical law.

QUESTIONS

1. Describe carefully how you would prepare Copper Oxide from Copper. How would you reduce it to metallic Copper?
2. When Hydrogen is passed over heated Copper Oxide what is formed in addition to Copper? How would you verify this?
3. What experiment would you perform to find out the weight of Copper which will combine with 8 grm. of Oxygen?
4. Who first formulated the Law of Conservation of Mass? State the Law and say how you would attempt to verify it. What is another name for it?

CHAPTER XII

BOYLE'S LAW. CHARLES' LAW. EQUIVALENT WEIGHTS. LAW OF MULTIPLE PROPORTIONS

Equivalent Weights of Metals

You have already studied (Part II, p. 22) the action of the common mineral acids on iron, zinc, tin, copper, and magnesium. In the case of Hydrochloric Acid and *dilute* Sulphuric Acid, when there was any action at all, Hydrogen was evolved. In no case except with Magnesium and *cold very dilute* Nitric Acid was Hydrogen evolved by the action of a metal on Nitric Acid.

You will now study the *quantitative* action of Hydrochloric Acid and dilute Sulphuric Acid on metals.

It is possible for you to measure the volume of Hydrogen liberated when a weighed amount of a particular metal dissolves in an acid. You can then find the **weights of various metals which liberate 1 grm. of Hydrogen. These weights are equivalent weights.**

A little difficulty arises owing to the variation in volume of a gas which accompanies changes in temperature and pressure. For purposes of comparison under similar conditions, standards of temperature and pressure have to be fixed, and these standards are 0° C. and 760 mm. respectively. These are often referred to as S.T.P. or N.T.P.—"Standard temperature and pressure" or "Normal temperature and pressure."

It is necessary for you to find out how the volume of a given mass of gas varies with the pressure and with the temperature, so that you may be able to adjust the volume of gas to S.T.P.

Relation between the Volume and Pressure of a Gas at Constant Temperature

The Hon. Robert Boyle, son of the Earl of Cork, was born in 1627. While still a child he learnt to speak Latin and French, and at the age of eight he went to Eton. He left at the age of eleven and for six years he travelled abroad with a French tutor.

Robert Boyle

On returning to England in 1644 he devoted his life to scientific study. He took a prominent place in the band of inquirers known as the "Invisible College"—a society devoted to the study of science and which grew into the Royal Society, the oldest scientific society in Great Britain and one of the oldest in Europe.

Amongst other things which occupied the attention of this young and enthusiastic scientist was the relation between the volume and the pressure of air. From common-sense observations Boyle knew that the volume diminished as the pressure increased. He suspected that the pressure and volume were in reciprocal proportion. By this is meant that if the pressure is doubled, the volume is halved. If the pressure is increased three times, the volume becomes one-third, and so on. The experiments which he performed in establishing the Law that now bears his name are best described in his own words: "We took then a long glass tube (fig. 121), which, by a dextrous hand and the help of a lamp, was in such a manner crooked at the bottom, that the part turned up was almost parallel to the rest of the tube, and the orifice of this shorter leg of the syphon (if I may so call the whole instrument) being hermetically sealed, the length of it was divided into inches (each of which was subdivided into eight parts by a straight list of paper, which, containing those divisions, was carefully pasted all along it. Then putting in as much quicksilver as served to fill the arch or bended part of the syphon, that the mercury standing in a level might reach in the one leg to the bottom of the divided paper, and just to the same height or horizontal line in the other, we took care, by frequently inclining the tube, so that the air might freely pass from one leg into the other by the sides of the mercury (we took, I say, care), that the air at last included in the shorter cylinder should be of the same laxity with th

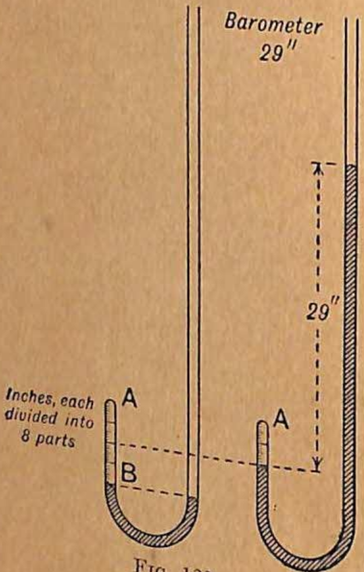

Fig. 121.

rest of the air about it. This done, we began to pour quicksilver into the longer leg of the syphon, which by its weight pressing up that in the shorter leg, did by degrees straighten the included air; and continuing this pouring in of quicksilver till the air in the shorter leg was by condensation reduced to take up but half the space it possessed (I say possessed, not filled) before, we cast our eyes upon the longer leg of the glass, upon which we likewise pasted a list of paper carefully divided into inches and parts, and we observed, not without delight and satisfaction, that the quicksilver in that longer part of the tube was 29 inches higher than the other. Now that this observation does both very well agree with and confirm our hypothesis, will be easily discerned by him that takes notice what we teach: and Monsieur Pascal and our English friend's (Mr Townley's) experiments prove, that the greater the weight is, that leans upon the air, the more forcible is its endeavour of dilatation, and consequently its power of resistance (as other springs are stronger when bent by greater weights). For this being considered, it will appear to agree rarely well with the hypothesis, that as according to it the air in that degree of density, and correspondent measure of resistance, to which the weight of the incumbent atmosphere had brought it, was unable to counterbalance and resist the pressure of a mercurial cylinder of about 29 inches, as we are taught by the Torricellian experiment; so here the same air being brought to a degree of density about twice as great as that it had before, obtains a spring twice as strong as formerly. As may appear by its being able to sustain or resist a cylinder of 29 inches in the longer tube, together with the weight of the atmospherical cylinder that leaned upon those 29 inches of mercury; and, as we just now inferred from the Torricellian experiment, was equivalent to them." The results of the experiments here detailed are given in the following table (p. 100).

A simple and effective modification of the apparatus used by Boyle will now be described, and you should try to verify **Boyle's Law,** which states that *the volume of a given mass of gas varies inversely as the total pressure to which it is subjected, provided the temperature remains constant.*

Two pieces of glass tubing, one about 5 mm. bore and the

A TABLE OF THE CONDENSATION OF THE AIR

A	B	C	D	E
12	00	B added to $29\frac{1}{8}$ makes D.	$29\frac{2}{16}$	$29\frac{2}{16}$
$11\frac{1}{2}$	$01\frac{7}{16}$		$30\frac{9}{16}$	$30\frac{6}{16}$
11	$02\frac{13}{16}$		$31\frac{15}{16}$	$31\frac{12}{16}$
$10\frac{1}{2}$	$04\frac{6}{16}$		$33\frac{8}{16}$	$33\frac{1}{7}$
10	$06\frac{3}{16}$		$35\frac{5}{16}$	35
$9\frac{1}{2}$	$07\frac{14}{16}$		37	$36\frac{15}{19}$
9	$10\frac{2}{16}$		$39\frac{5}{16}$	$38\frac{7}{8}$
$8\frac{1}{2}$	$12\frac{8}{16}$		$41\frac{10}{16}$	$41\frac{2}{17}$
8	$15\frac{1}{16}$		$44\frac{3}{16}$	$43\frac{11}{16}$
$7\frac{1}{2}$	$17\frac{15}{16}$		$47\frac{1}{16}$	$46\frac{3}{5}$
7	$21\frac{3}{16}$		$50\frac{5}{16}$	50
$6\frac{1}{2}$	$25\frac{3}{16}$		$54\frac{5}{16}$	$53\frac{10}{13}$
6	$29\frac{11}{16}$		$58\frac{13}{16}$	$58\frac{2}{8}$
$5\frac{3}{4}$	$32\frac{3}{16}$		$61\frac{5}{16}$	$60\frac{18}{23}$
$5\frac{1}{2}$	$34\frac{15}{16}$		$64\frac{1}{16}$	$63\frac{6}{11}$
$5\frac{1}{4}$	$37\frac{15}{16}$		$67\frac{1}{16}$	$66\frac{4}{7}$
5	$41\frac{9}{16}$		$70\frac{11}{16}$	70
$4\frac{3}{4}$	45		$74\frac{2}{16}$	$73\frac{11}{19}$
$4\frac{1}{2}$	$48\frac{12}{16}$		$77\frac{14}{16}$	$77\frac{2}{3}$
$4\frac{1}{4}$	$53\frac{11}{16}$		$82\frac{12}{16}$	$82\frac{4}{17}$
4	$58\frac{2}{16}$		$87\frac{14}{16}$	$87\frac{3}{8}$
$3\frac{3}{4}$	$63\frac{15}{16}$		$93\frac{1}{16}$	$93\frac{1}{5}$
$3\frac{1}{2}$	$71\frac{5}{16}$		$100\frac{7}{16}$	$99\frac{6}{7}$
$3\frac{1}{4}$	$78\frac{11}{16}$		$107\frac{13}{16}$	$107\frac{7}{13}$
3	$88\frac{7}{16}$		$117\frac{9}{16}$	$116\frac{4}{8}$

A The number of equal spaces in the shorter leg that contain the same parcel of air diversely extended.

B The height of the mercurial cylinder in the longer leg that compressed the air into those dimensions.

C The height of the mercurial cylinder that counterbalanced the pressure of the atmosphere.

D The aggregate of the two last columns, B and C, exhibiting the pressure sustained by the included air.

E What that pressure should be according to the hypothesis that supposes the pressure and expansion to be in reciprocal proportion.

You should verify several values of column E by calculation from A, using Boyle's Law.

other wider and 12 in. long, are connected by about 2 ft. of pressure tubing which is securely wired on to the ends of the glass tubes. Mercury is then poured into A until it stands at a level approximately one-third the length of the tubes (fig. 121A). At the moment both tubes are open, and the height of the mercury will be the same in both tubes because pressure is the same in both tubes. What is this pressure? Will this pressure always be acting in the case of an open tube? Seal off the end of the tube B, making the top as flat as possible. Raise the tube A and say what happens. Lower the tube A and again say what happens. Examine the conditions in the positions shown in figs. 122 and 123. In fig. 122 the line of equal pressure is XX. The total pressure at XX in tube A is made up of atmospheric pressure + H cm. of mercury, ∴ the pressure of the air in B is greater than atmospheric pressure. In fig. 123 again the line of equal pressure is XX. The pressure at XX in tube A is atmospheric pressure, and this is equal to the pressure of the air in B + H cm. of mercury, ∴ the pressure of the air in B = Atmospheric Pressure − pressure due to H cm. of mercury.

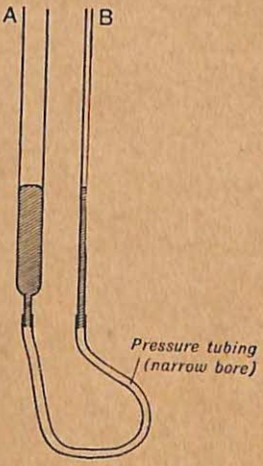

FIG. 121A.

Tabulate results as follows :—

Atmospheric Pressure 75·8 cm. of mercury.

Pressure H cm. of mercury	Total pressure cm. of mercury	Volume (measured as length) cm.	P × V
− 4·3	71·5	13·8	986·70
− 9·2	66·6	14·8	985·68
− 12·9	62·9	15·7	988·63
+ 7·9	83·7	11·8	989·66
+ 13·3	89·1	11·1	989·0
+ 5·4	79·8	12·4	989·5

The readings (p. 101) show that as the total pressure gets bigger, the volume decreases in the same proportion, whereas when the total pressure is decreased, the volume increases in the same proportion, thus verifying Boyle's Law.

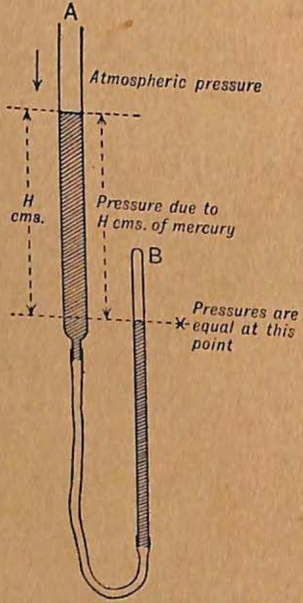
A
Atmospheric pressure
H cms.
Pressure due to H cms. of mercury
B
Pressures are equal at this point

FIG. 122.

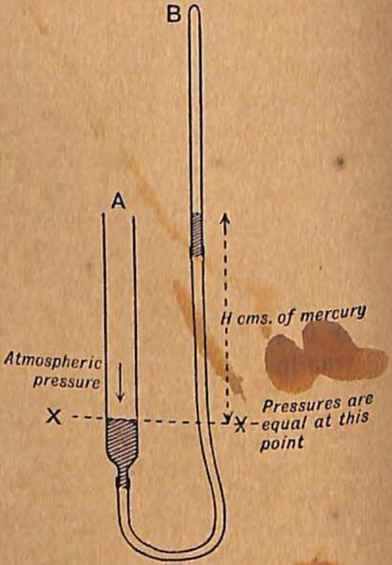

FIG. 123.

Charles' Law

You have already learnt that gases expand on being heated, and that different gases expand equally when heated under the same conditions.[1]

The following experiment will enable you to determine the fractional increase in volume per degree rise in temperature.

A flask about 200 c.c. capacity is thoroughly dried and fitted with a tight-fitting rubber stopper through which passes a piece of glass tubing. To the end of this tubing a piece of rubber tubing is connected so that the flask may be closed by a clip.

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[1] *General Science*, Part I, p. 81.

The flask is heated in a water-bath (old sweet tins holding about 1 gallon are very useful for this purpose), and kept at the boiling-point of water for some minutes (fig. 124). The clip is then put on the rubber tubing and the flask removed to another water-bath containing ice. After standing in this bath for a few minutes the clip is opened under the ice-cold water, and water enters the flask. The flask is then removed from the cold water.

It is clear that the air left in the flask at 0° C. is the amount that filled the flask at 100° C., and the volume of the water is the amount this volume of air has expanded.

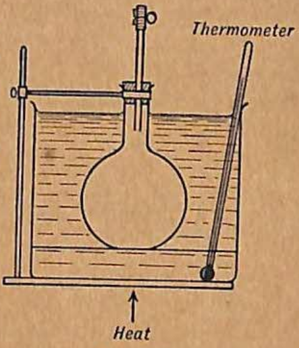

Fig. 124.

The following results were obtained as the result of a class experiment:—

Total volume of flask	213 c.c.
Volume of water which enters . . .	57 c.c.
∴ volume of air at 0° C. which filled the flask at 100° C.	156 c.c.

∴ 156 c.c. expand 57 c.c. on being heated from 0° to 100° C.

$$\therefore \text{ 1 c.c. expands } \frac{57}{156 \times 100} \text{ on being heated through } 1^\circ \text{ C.}$$

$$= \frac{1}{273 \cdot 6}.$$

Thus the air has expanded $\frac{1}{273}$ of its volume at 0° for 1° rise in temperature.

From the above experiment it follows that a gas will contract $\frac{1}{273}$ of its volume at 0° C. for every degree fall in temperature. Thus at -273° C. theoretically the gas would have no volume. As a matter of fact, all known gases liquefy before this temperature, and -273° C. has been called the *absolute zero of* *temperature.* This is recognised to be the lowest temperature which it is possible to attain. At this temperature there would be no heat left in the gas. As you may expect, this temperature has never actually been attained, although at Leiden in Holland, where scientists specialise in low temperature research, Kammerlingh Onnes (who died in 1929) succeeded in approaching within a degree of it.

Scientists find very useful an *absolute scale of temperature* the zero of which is −273° C. and the degrees of which are equal to centigrade degrees. On this scale −273° C. is called 0° absolute, or 0° Kelvin (0° K.) in honour of Lord Kelvin, who first proposed this scale. On it the freezing-point of water would be 273° K., and the normal boiling-point 373° K.

If V is the volume of a gas at 0° C., and V_1 is its volume at 20° C., then

$$\begin{aligned} V_1 &= V + \frac{20V}{273} \\ &= \frac{(273+20)V}{273} \\ &= \frac{293}{273}V \\ \therefore \frac{V_1}{V} &= \frac{293}{273}. \end{aligned}$$

If V is the volume of a gas at 0° C., and V_t is its volume at t° C., then

$$\begin{aligned} V_t &= V + \frac{t}{273}V \\ \therefore V_t &= \frac{(273+t)V}{273} \\ \therefore \frac{V_t}{V} &= \frac{273+t}{273}. \end{aligned}$$

It is thus seen that the volume of a given mass of gas varies directly as the absolute temperature, provided the pressure remains constant. This is called Charles' Law.

Boyle's Law and Charles' Law may be combined thus:

$$\frac{V_1P_1}{T_1}=\frac{V_2P_2}{T_2},$$

where $V_1T_1P_1$ mean the volume at a certain temperature T_1 on the **absolute** scale and under a certain pressure P_1, and V_2, T_2, P_2 mean a volume under another set of conditions of temperature and pressure.

If a Gas occupied 300 c.c. at 20° C. and 750 mm., what Volume would it occupy at 0° C. and 760 mm. Pressure?

First change the Centigrade temperature to absolute temperature.

300 c.c. $=V_1$	V_2 is required
293° K. $=T_1$	273° K. $=T_2$
750 mm. $=P_1$	760 mm. $=P_2$.

$$\therefore\ \frac{300\times750}{293}=\frac{V_2\times760}{273}$$

$$\therefore\ V_2=\frac{750\times300\times273}{760\times293}=275{\cdot}8 \text{ c.c. (by logs.)}.$$

Physiological Effects of Working in High Pressures

In diving and similar operations where men are subjected to high air-pressures, the amount of air dissolved in the body tissues and blood-stream increases. The amount dissolved is approximately proportional to the pressure. The Oxygen is disposed of by absorption in the blood, but when the pressure is released the Nitrogen tends to separate in the form of bubbles—very much like Carbon Dioxide separates from soda-water fresh from the siphon. The rapid separation of Nitrogen produces severe body pains, and may even produce death. It is necessary, therefore, that the change should be made in slow stages so as to allow the Nitrogen to escape from the tissues through the lungs. After a stay of forty-five minutes at a depth of 200 ft., two hours or more is necessary to bring a diver safely to the surface.

The U.S. Bureau of Standards have in recent years made experiments to find out if the Nitrogen of the air can be replaced with another gas with beneficial effects. It is found that Helium not only dissolves less than Nitrogen in the blood-stream, but is got rid of much more quickly. As a result, divers supplied with air in which Nitrogen is replaced by Helium can come to the surface safely in about one-sixth of the time necessary in ordinary air.

The apparatus by which the experiments were carried out is shown in the accompanying illustrations, which are reproduced by permission of the U.S. Bureau of Standards and the editor of *Nature*.[1]

Pressure chamber for exposing men to high pressure for the study of caisson disease and diving problems. Outside view looking through doors into air lock and main chamber. This chamber is capable of withstanding 40 atmospheres pressure. It is equipped with telephone, electric lights, fan, heater, and plate-glass windows.

Determination of the Equivalent Weight of a Metal by Measuring the Hydrogen displaced from an Acid

Fit up the apparatus shown in fig. 125. As this apparatus is frequently used in measuring the volume of gas evolved during a chemical reaction, it is well to learn the precautions which must be taken to ensure a good result. Proceed as follows :—

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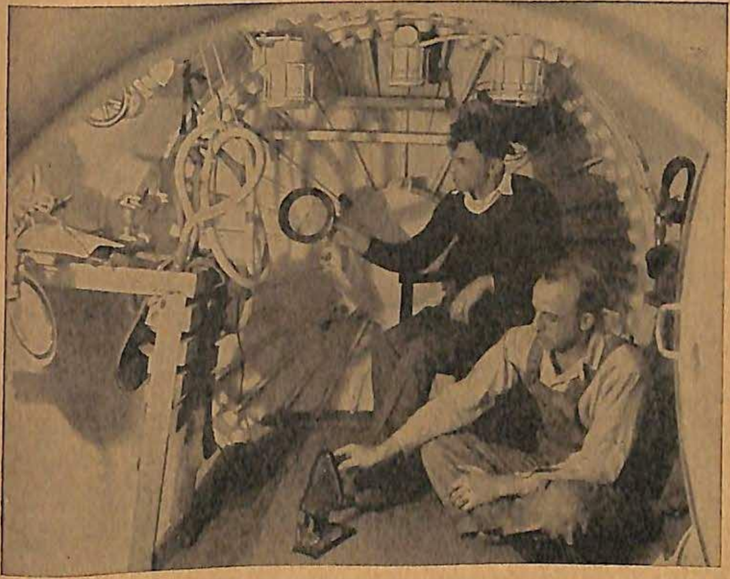
[1] For a full account, see *Nature*, Apr. 14, 1928, vol. cxxi, p. 577.

(*a*) Clean and weigh a piece of zinc foil. (Use about 1 sq. in.)

(*b*) Fill the tube B with water by opening the clip C, removing the flask, and blowing down the tube at A. Note that the water now siphons from the bottle B into the measuring cylinder E. *When will the water cease to flow from D into E?*



Interior of chamber with test apparatus. Note electric lights, pressure gauge, control valve. There is a device for passing in and out apparatus and food. Also there are controls outside as well as inside, and in the event of a man's judgment being impaired the inside controls could be put out of action by an outside observer. Thus too-rapid release of pressure by those inside could be avoided.

(*c*) Put the flask back again and find out if the water ceases to flow into the measuring cylinder. If it does not, then the apparatus is not gas-tight, and the stoppers and rubber tubing at C should be examined for a leak. *It is* *useless to proceed with the experiment until the apparatus is made gas-tight.*

(*d*) If the apparatus is gas-tight, close the clip C, remove the flask, and pour in some dilute Sulphuric Acid. It is advisable to use a funnel so that the acid does not wet the neck of the flask.

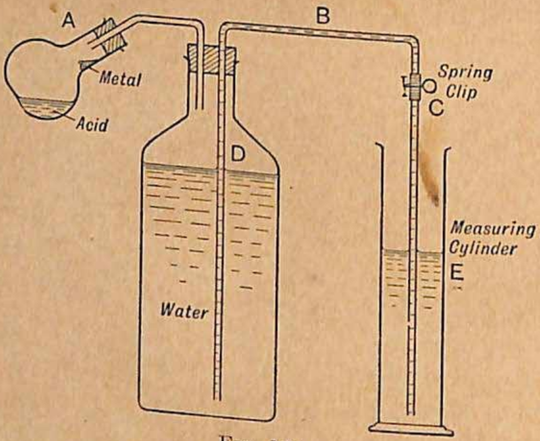


Fig. 125.

(*e*) Hold the flask with the neck horizontal, and slip in the weighed zinc foil, allowing it to rest in the neck. Carefully fix the flask on the stopper, giving it a final twist to fix it firmly, but being very careful not to allow the metal to slip into the acid.

(*f*) Pour sufficient water into the measuring cylinder to cover the end of the delivery tube. Open the clip, tilt the measuring cylinder until the level of the water in it is at the same height as that in the bottle. While the cylinder is held in this position close the clip and then put the measuring cylinder on the bench again.

(*g*) Gently raise the whole apparatus until the delivery tube is *just above* the water in the cylinder. Read the volume of water in the cylinder.

(*h*) Lower the apparatus in position again, tap the flask so that the metal drops into the acid, and open the clip.

(*i*) When the action ceases, cool the flask to the temperature of the room and then tilt the measuring cylinder to adjust the levels in the bottle and cylinder once more, and *with the cylinder in this position* close the clip C.

(*j*) Lift the apparatus so that the delivery tube is no longer in the water in E and take the reading.

(*k*) Note the temperature and pressure of the atmosphere at the time of the experiment.

Suppose 0·5 grm. of Zinc when acted on by dilute Sulphuric Acid yield 183 c.c. of Hydrogen at 16° C. and 750 mm. pressure.

Let V_1, T_1, P_1 be respectively the volume, absolute temperature, and pressure as recorded in the *laboratory*, and V.T.P. be the volume at normal temperature and pressure. Then

$$\frac{V_1P_1}{T_1} = \frac{VP}{T}$$

$$\therefore \frac{183 \times 750}{289} = \frac{V \times 760}{273}$$

$$\therefore V = \frac{183 \times 750 \times 273}{289 \times 760} \text{ c.c.}$$

Now 1000 c.c. of Hydrogen at N.T.P. weigh 0·09 grm.

∴ the weight of the above volume of Hydrogen

$$= \frac{183 \times 750 \times 273}{289 \times 760} \times \frac{0{\cdot}09}{1000} \text{ grm.}$$

$$= 0{\cdot}01536 \text{ grm.}$$

∴ 0·01536 grm. of Hydrogen is displaced by 0·5 grm. of Zinc.

∴ 1 grm. of Hydrogen is displaced by $\frac{0{\cdot}5}{0{\cdot}01536} = 32{\cdot}5$ grm. of Zinc.

32·5 grm. of Zinc displace 1 grm. of Hydrogen from an acid. 12·0 grm. of Magnesium displace 1 grm. of Hydrogen from an acid.

32·5 and 12 are equivalent weights of Zinc and Magnesium.

Note—32·5 *grm.* of Zinc displace 1 *grm.* of Hydrogen; 32·5 *tons* of Zinc displace 1 *ton* of Hydrogen.

By this method the following equivalents may be determined:[1] Zinc 32·5, Iron 28, Aluminium 9, Magnesium 12, Calcium 20, Tin 60.

Displacement of one Metal by Another

When you place a bright piece of Iron in a solution of Copper Sulphate the Iron becomes coated with Copper, but at the same time some Iron goes into solution. The idea of equivalent weights suggests that if 28 grm. of Iron goes into solution, the weight of Copper deposited would be the equivalent weight of Copper.

Zinc and Iron both displace Copper from a solution of Copper Sulphate, and Zinc displaces Lead from a solution of Lead Acetate.

Determination of the Equivalent Weight of Lead by Displacement from Lead Acetate

Clean about 2 grm. of zinc foil with emery paper and weigh. Pour some Lead Acetate solution into a beaker, and drop the zinc, which is carefully cut into very thin strips, into the Lead Acetate solution. Note the crystals of lead which deposit on the surface of the zinc. The zinc slowly disappears. It is wise to leave the zinc in the Lead Acetate solution overnight, when it will have completely gone into solution and displaced a corresponding weight of lead.

Pour the solution containing the lead in suspension through a counterpoised filter paper. Wash the lead well with water. Dry by pouring alcohol over it and then leaving in the water-oven for a few minutes.

The following results were obtained by a class for this experiment :—

2 grm. zinc give 6·42 grm. lead
∴ 32·5 grm. zinc give 104·32 grm. lead
∴ 104·32 is the equivalent weight of lead.

Repeat the above experiment, using zinc or iron and a solution of Copper Sulphate, or Magnesium and a solution of Silver Nitrate.

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[1] A volume greater than 500 c.c. may be obtained with Aluminium Calcium, Magnesium, and suitable arrangements must be made.

Determination of the Equivalent Weight of Oxygen

In the case of many elements it is more convenient to determine what weight combines with a known weight of Oxygen. If, therefore, we know the weight of Oxygen which combines with 1 grm. of Hydrogen, *i.e.* the equivalent weight of Oxygen, we can use this as a means of determining equivalents.

You have already learnt [1] that Hydrogen combines with Oxygen to form water, and also that two volumes of Hydrogen are united with one volume of Oxygen in water. Let us now determine the *weight* of Oxygen which combines with 1 grm. of Hydrogen.

Fit up the apparatus shown in fig. 126. Prepare Hydrogen by the action of Hydrochloric Acid on zinc, wash it by passing it through water, and then dry it by passing it through Calcium Chloride. Weigh the tube A containing Copper Oxide (made by heating bits of Copper wire or turnings in air) and weigh the Calcium Chloride tube B. It may be advisable to attach another Calcium Chloride tube to B to be quite sure all the water is absorbed. Remember the precaution necessary before heating the tube A (see p. 94). As the Hydrogen passes over the heated Copper Oxide it combines with the Oxygen to form water, which is collected in the tube B. The loss in weight of the tube A gives the weight of Oxygen present

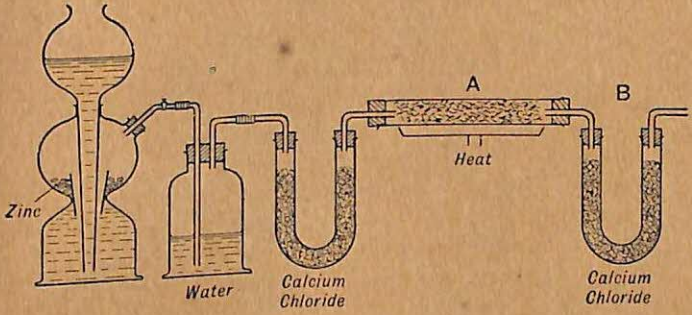

FIG. 126.

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[1] *General Science*, Part II, p. 15.

in the weight of water collected in B. By subtracting the weight of Oxygen from the weight of water, the weight of Hydrogen can be found. You can then find the weight of Oxygen which combines with 1 grm. of Hydrogen.

Record your result as follows :—

Weight of tube A + Copper Oxide . . . .
,, ,, + Copper . . . .
∴ weight of Oxygen . . . .
Weight of tube B . . . .
,, ,, + water . . . .
∴ weight of water . . . .
∴ weight of Hydrogen . . . .
∴ weight of Oxygen which combines with 1 grm. of Hydrogen is . . . .

Determination of Equivalent Weights by Converting a Known Weight of an Element into its Oxide, or by Reducing a Metallic Oxide to the Metal

This method has already been used in the case of copper. Cupric Oxide was prepared and then reduced to copper in the experiment described on pp. 92–95. Also, if the copper used in the experiment performed by section I (see p. 92) were weighed before treatment with Nitric Acid, and then the final oxide weighed, the equivalent weight could be calculated.

Equivalent Weight of Tin by Conversion into its Oxide

Weigh accurately in a small weighed porcelain basin about 2 grm. of tin, cover the basin with a clock-glass and then add cautiously by means of a dropping tube some Nitric Acid (strength 1 concentrated acid + 1 water). Gently heat the basin on a steam-bath until all the action is over, then remove the clock-glass, wash back anything that has spurted upon it, and evaporate to dryness on the steam-bath. When the contents of the basin are dry, heat it over a Bunsen flame, at first gently, then more strongly, until there is no further loss in weight. The final product is Stannic Oxide, and the equivalent weight of tin can be found from the results obtained.

Compare the value of the equivalent of tin determined by oxidation with that obtained when tin displaces Hydrogen from an acid. In the former case it is 29·5, and in the latter case 59. Note these are in the simple ratio of 1 : 2.

The Law of Multiple Proportions

It often happens that the same two elements combine together to form ·two or more compounds. For example, Carbon and Oxygen combine to form Carbon Dioxide and Carbon Monoxide; Copper and Oxygen combine to form Cuprous Oxide and Cupric Oxide; Iron and Chlorine give Ferrous Chloride and Ferric Chloride. It has been found that when these pairs of compounds are analysed a relationship exists between the amounts of one of the elements combined with a fixed amount of the other element.

You have just observed that 29·5 grm. of tin on one occasion are equivalent to 8 grm. of Oxygen, but 59 grm. of tin are equivalent to 8 grm. of Oxygen on another occasion. In this case the amounts of tin chemically equivalent to 8 grm. of Oxygen are in the simple ratio of 1 : 2.

In the case of Carbon Dioxide and Carbon Monoxide the amounts of Carbon combined with one part by weight of Oxygen are in the ratio 1 : 2; in the case of the two Chlorides of iron, Ferrous Chloride and Ferric Chloride, the amounts of iron combined with a fixed amount of Chlorine are in the ratio 3 : 2.

These results and others like them are summed up in the general statement known as **The Law of Multiples** thus: **If two elements combine together to form two or more compounds, then the weights of one of these elements which combine with a fixed weight of the other element bear a simple numerical relation to one another**; or, **If an element has two or more equivalent weights they are simple multiples of a common factor.**

It is not possible at this stage to determine the composition of all of the above compounds, but you will deal with most of them some time during your chemistry course.

To Verify the Law of Multiple Proportions

We shall use Cuprous Oxide and Cupric Oxide to verify the law. Care should be taken to procure *pure* specimens of the two oxides, and to dry them thoroughly by heating gently and then cooling in a desiccator. The apparatus used is exactly the same as that used when verifying the Law of Constant Proportions, and the same precautions should be taken. See pp. 92–95.

The following result was obtained in a class experiment :—

	Cuprous Oxide experiment	Cupric Oxide experiment
	grm.	grm.
Weight of porcelain boat .	5·31	5·21
,, ,, boat + oxide .	5·98	5·82
∴ ,, ,, oxide . .	0·67	0·61
,, ,, boat + Copper (after expt.) .	5·90	5·69
∴ ,, ,, Copper . .	0·59	0·48
∴ ,, ,, Oxygen . .	0·08	0·13
∴ ,, ,, Copper which combines with 1 grm. of Oxygen . . .	7·37	3·69
and 7·37 : 3·69 = 2 : 1		

The weights of copper combining with a fixed weight of Oxygen bear the simple numerical relationship 2 : 1. Thus the Law of Multiples is verified in the case of Copper and Oxygen.

QUESTIONS

1. How would you attempt to establish the relation between pressure and volume of a given mass of gas at a constant temperature? State clearly the law which expresses this relationship.
2. How would you show that all gases expand equally if the pressure is constant? Describe an experiment to determine the coefficient of expansion of Oxygen at constant pressure.
3. A gas occupies a volume of 300 c.c. at 15° C. and 740 mm. pressure. What will it occupy at N.T.P.?

4. What volume will 250 c.c. of gas at N.T.P. occupy when the temperature is raised to 20° C. and the pressure to two atmospheres?

5. When 0·18 grm. of a metal was dissolved in Hydrochloric Acid, 250 c.c. of Hydrogen, measured at 15° C. and 720 mm. pressure, were evolved. Calculate the equivalent of the metal.

6. State the Law of Constant Composition. You are required to verify this law by using the black Oxide of Copper, and for this purpose you are supplied with specimens of Copper Nitrate and Copper Carbonate. State clearly (*a*) how you would prepare specimens of Copper Oxide, (*b*) how you would use them to verify the law.

7. Two metallic chlorides contain respectively 55·9 and 65·5 per cent. of Chlorine. Show how the above figures may be used to illustrate the Law of Multiple Proportions. State the law.

CHAPTER XIII

SYMBOLS, FORMULÆ, AND EQUATIONS

From the beginning of time men have tried to represent various things by signs or symbols. In ancient manuscripts we find curious symbols for the four "elements"—earth, air, fire, and water.

There was a secrecy about the work of the early chemists—the alchemists, as they were called—and symbols were used to keep this secrecy.

Nowadays symbols are used for a very different purpose. They stand for elements, and by obeying certain laws we are able to build up formulæ for compounds and find out the quantities of various compounds or elements which react with one another.

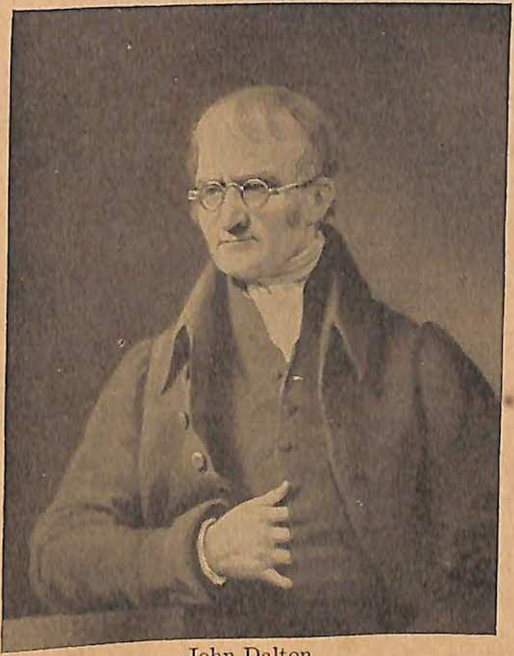
Atoms and Molecules

In order that we may more clearly understand certain chemical reactions which take place, it is convenient for us to regard matter as being composed of extremely small particles. These particles are so small that the most powerful microscope cannot reveal them; they are called **atoms**. When the metal Magnesium was burnt in Oxygen a white oxide, Magnesium Oxide, was formed. If we assume that the metal Magnesium is made up of atoms, and that Oxygen gas is made up of atoms, we can say that atoms of Magnesium combine with atoms of Oxygen to form new particles of Magnesium Oxide.

These new particles are called "molecules." An **atom** may be defined as the smallest particle that can take part in a chemical reaction. A **molecule** may be defined as the smallest particle of an *element* or *compound* that can exist alone and possess the chemical properties of that element or compound.

Atomic Weight

John Dalton in 1808 put forward the Atomic Theory and proceeded to show how this theory would help us to understand the Law of Constant Composition and the Law of Multiples. It certainly enables us to do this, and also enables us to build up formulæ for substances and to determine the quantities of substances taking part in chemical reactions. He suggested that the atoms of a particular element are all alike, but that they are different from the atoms of another element. In particular, all the atoms of one element have the same weight, but this weight differs in different elements. The atomic weights which Dalton assigned to the elements were really equivalent or combining weights, those which are now given are of later date than Dalton. An atom of Oxygen is about sixteen times as heavy as an atom of Hydrogen, an atom of Copper is about sixty-three times as heavy as an atom of Hydrogen. Hydrogen is the lightest atom known, and if we call its weight 1, the weight of the Oxygen atom would be 16,



John Dalton

the weight of the Copper atom 63, and so on. **The weight of an atom of an element compared with the weight of an atom of Hydrogen is called the Atomic Weight of the element.** It is a ratio (like **relative density** and **specific heat**) and is a **number**, not a weight. If we attach a unit of weight to the atomic weight it must be clearly stated thus: 16 grm. would be called the **gram atomic weight of Oxygen**, 16 lb. would be called the **pound** atomic weight of Oxygen.

Gay-Lussac, the chemist who extended Dalton's conception of the Atomic Theory.

The atomic weight of an element must not be confused with the absolute weight of the atom. An atom of Hydrogen weighs $1{\cdot}66 \times 10^{-24}$ grm.

When two elements combine, Dalton suggested that combination takes place between individual atoms. Iron and sulphur combine to form a new substance, Iron Sulphide.[1] Dalton would explain this by saying one atom of iron combined with one atom of sulphur to form a "new atom" (a molecule) of iron sulphide. If ● stands for an atom of iron, and ○ for an atom of sulphur, we should represent a molecule of iron sulphide as ●○.

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[1] See *General Science*, Part II, p. 19.

It will be seen that Dalton's theory makes the Law of Constant Composition easy to understand, because all molecules of Iron Sulphide will have the weights of iron and sulphur always in the proportion of the atomic weights of iron and sulphur respectively, and therefore the weights of iron and of sulphur in a given weight of Iron Sulphide are always constant.

Now apply Dalton's atomic theory to the two oxides of copper and see how the Law of Multiples follows.

Let ⊕ stand for copper and □ for Oxygen, then, seeing that combination must take place between *whole* atoms, Cuprous Oxide may be represented as $\begin{matrix}\oplus\\ \oplus\end{matrix}\square$ and Cupric Oxide as ⊕□. Remembering that all the atoms of copper have the same weight as each other, and all the atoms of Oxygen have the same weight as each other (but different from those of copper), the weights of copper combined with a fixed weight of Oxygen in the two compounds are in the ratio 2 : 1.

It may be, of course, that two elements combine as follows: Let atoms of element A be represented as Δ and those of element B as ⊠. In compounds (1) $\begin{matrix} & \boxtimes\\ \Delta & \boxtimes\\ \Delta & \\ & \boxtimes\end{matrix}$ and (2) $\Delta\begin{matrix}\boxtimes\\ \boxtimes\end{matrix}$. You will see how the law follows if you let the atomic weight of A be x and the atomic weight of B be y. Then in (1) $2x$ weight units of A are combined with $3y$ weight units of B, and in (2) x weight units of A are combined with $2y$ weight units of B.

(2) may be written as $2x$ weight units of A combined with
$4y$ weight units of B

and

(1) is $2x$ weight units of A combined with
$3y$ weight units of B.

Therefore the weights of B combining with a fixed weight of A are in the proportion of 4 : 3.

The following table gives the symbols now used for the commoner elements, the atomic weights of these elements, and also the formula of a common compound of each metal named. It is well to memorise these at this stage.

Name of element	Symbol	Atomic weight	Name of common compound of the metal	Formula of the compound
Calcium	Ca	40	Calcium Carbonate	$CaCO_3$
Aluminium	Al	27	Aluminium Oxide (Alumina)	Al_2O_3
Magnesium	Mg	24	Magnesium Sulphate (Epsom salts)	$MgSO_4$
Potassium	K	39	Potassium Nitrate (Nitre)	KNO_3
Silver	Ag	108	Silver Chloride	AgCl
Sodium	Na	23	Sodium Chloride (Common salt)	NaCl
Tin	Sn	119	Stannous Chloride Stannic Chloride	$SnCl_2$ $SnCl_4$
Iron	Fe	56	Ferrous Sulphate (Green vitriol) Ferric Chloride	$FeSO_4$ $FeCl_3$
Lead	Pb	207	Lead Monoxide (Litharge)	PbO
Zinc	Zn	65	Zinc Oxide	ZnO
Hydrogen	H	1	Non-metals	
Oxygen	O	16		
Nitrogen	N	14		
Carbon	C	12		
Phosphorus	P	31		
Sulphur	S	32		
Chlorine	Cl	35·5		
Bromine	Br	80		
Iodine	I	127		

Formulæ of the Common Acids

Carbonic Acid, H_2CO_3
Hydrochloric Acid, HCl
Sulphuric Acid, H_2SO_4
Nitric Acid, HNO_3

These formulæ stand for one molecule in each case, thus:

HNO_3 means "one molecule of Nitric Acid."

This molecule contains one atom of Hydrogen, one atom of Nitrogen, and three atoms of Oxygen combined together.

Similarly the formula H_2O stands for "one molecule of water."

This molecule contains two atoms of Hydrogen and one atom of Oxygen united together.

Molecules are *very* small particles. Some idea of their size may be obtained by imagining a drop of water which drips from the water-tap to be magnified until it is as big as the earth, then the *molecules* of water in the drop would only be about the size of golf balls. Atoms are smaller still.

You have already learnt [1] that acids will form salts; now let us see how the formulæ of these salts are built up.

Carbonic Acid, H_2CO_3, can form Carbonates and Bicarbonates by replacing the whole or part of the Hydrogen by a metal, thus Carbonates all contain the group $-(CO_3)$, Bicarbonates $-(HCO_3)$. In the case of Carbonates two Hydrogen atoms in the molecule of Carbonic Acid have been replaced by a metal, and in the case of Bicarbonates one atom of Hydrogen in the molecule of Carbonic Acid has been replaced by a metal.

Sulphuric Acid, H_2SO_4, can also form two classes of salts: (*a*) Sulphates in which the two Hydrogen atoms in the molecule of Sulphuric Acid are replaced by a metal, (*b*) Bisulphates in which one of the Hydrogen atoms in the molecule of Sulphuric Acid is replaced by a metal. Hence Sulphate molecules contain $-(SO_4)$ and Bisulphate molecules contain $-(HSO_4)$.

Hydrochloric Acid, HCl, can only form one class of salts (Chlorides), because the molecule has only one atom of Hydrogen to be replaced by a metal. Hence all Chloride molecules contain $-Cl$.

Nitric Acid, HNO_3, can only form one class of salts (Nitrates), because the molecule has only one atom of Hydrogen to be replaced by a metal.

Water, H_2O, may be considered as the molecule from which Oxides and Hydroxides are built up. In the case of Oxides both the Hydrogen atoms in the molecule are replaced by a metal (or non-metal). In the case of Hydroxides only one Hydrogen atom in the molecule is replaced by a metal. Oxides all contain $-O$ and Hydroxides $-(OH)$.

The number of atoms of Hydrogen with which one atom (or

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[1] *General Science*, Part II, pp. 23, 24.

one group of atoms) will combine is called the valency of the atom (or group of atoms).

In Carbonic Acid the group of atoms $(-CO_3)$ which form Carbonates is combined with two Hydrogen atoms. Thus we say $(-CO_3)$ is *di*-valent. It is represented for convenience thus: $(-CO_3)''$.

The group of atoms $(-HCO_3)$ from which Bicarbonates are formed is combined with one Hydrogen atom, $H-(HCO_3)$. Thus we say $(-HCO_3)$ is *mono*-valent. It is represented thus: $(-HCO_3)'$. Now study the following table :—

Carbonic acid	H_2CO_3	$(-CO_3)''$	divalent
	$H.(HCO_3)$	$(-HCO_3)'$	monovalent
Sulphuric acid	H_2SO_4	$(-SO_4)''$	divalent
	$H.(HSO_4)$	$(-HSO_4)'$	monovalent
Hydrochloric acid	HCl	$-Cl'$	monovalent
Nitric acid	HNO_3	$(-NO_3)'$	monovalent
Water	H_2O	$-O''$	divalent
	$H.OH$	$(-OH)'$	monovalent

You will find it a very interesting occupation to build up the simplest formulæ of various salts.

Suppose, for example, you wished to write the formula for **Calcium Sulphate.** The formula will have to contain Ca and SO_4. Refer to the table on p. 120 and note in Calcium Carbonate, $CaCO_3$, one atom of Calcium is united with one (CO_3) group. Now the CO_3 group is divalent (see above), and one atom of Calcium has replaced two atoms of Hydrogen in H_2CO_3. Therefore Calcium is divalent.

Also SO_4 is divalent; therefore one Calcium atom can combine with one $(-SO_4)$ group; therefore the simplest formula is $CaSO_4$.

Now try **Calcium Nitrate.**

Reasoning as before, the formula must contain Ca and $(-NO_3)$. It is necessary to test the valencies of the two parts and see that they balance. Calcium is divalent; $(-NO_3)$ is monovalent; therefore two of the monovalent group of atoms will be required to satisfy one of the divalent element Calcium. Therefore the formula is written $Ca^{\cdot\cdot}(NO_3)'_2$.

Now try **Aluminium Sulphate.**

The formula you have learnt for a compound of aluminium is that of Alumina, Al_2O_3. First determine the valency of the atom of aluminium. In this compound two atoms of aluminium are united to three atoms of Oxygen in the molecule of Alumina. But Oxygen is a divalent atom, therefore the six valencies will be distributed between two atoms of aluminium. The åtom of aluminium is therefore trivalent, *i.e.* $Al^{\cdots}$.

The formula of Aluminium Sulphate must contain Al and (SO_4). Aluminium, Al, is trivalent and the $(-SO_4)$ group is divalent (see H_2SO_4), therefore the formula will be $Al_2(SO_4)_3$. Note that the suffix multiplied by the valency of the metallic part of the salt will balance the suffix multiplied by the valency of the acid part of the salt.

$$Al_2^{\cdots}(SO_4)''_3 \qquad 2 \times 3 = 3 \times 2.$$

In building up a formula therefore, proceed as follows: first determine the valency of the metal by referring to the formula of the common compound which you have learnt, the valency of the non-metallic group can be determined from the table on p. 120. Having fixed these valencies, apply the appropriate suffix to balance the valencies.

Exercise

Determine the formulæ of

(1) Calcium Chloride,
(2) Aluminium Nitrate,
(3) Magnesium Hydroxide,
(4) Potassium Carbonate,
(5) Silver Sulphate,
(6) Sodium Bicarbonate,
(7) Ferrous Chloride,
(8) Ferric Sulphate,
(9) Lead Sulphate,
(10) Zinc Nitrate,
(11) Calcium Bicarbonate,
(12) Magnesium Oxide.

Now let us consider the use of

Chemical Equations

The substances which take part in a chemical reaction, and the products of the reaction, can be represented by formulæ. If the reaction is expressed so that the reacting substances balance the products of the reaction, the expression is a chemical equation, *e.g.* when Hydrochloric Acid acts on chalk Carbon Dioxide, Calcium Chloride, and water are formed. Suppose we wish to express this by an equation. The reacting substances are HCl and $CaCO_3$. The products are CO_2, $CaCl_2$, H_2O.

$\therefore$ $CaCO_3 + HCl \longrightarrow CO_2 + CaCl_2 + H_2O$ represents the reacting substances and the products, but if you look carefully you will see that the two sides do not balance. There is only one atom of Chlorine on the left and two atoms on the right, *and you cannot alter the formula* $CaCl_2$, *as this is fixed by the valencies of* Ca'' *and* Cl'. Nor can we make the formula for Hydrochloric Acid HCl_2. We can, however, take two molecules of HCl and write the equation

$$CaCO_3 + 2HCl \longrightarrow CO_2 + CaCl_2 + H_2O.$$

Translated into words this means one molecule of Calcium Chloride reacts with two molecules of Hydrogen Chloride to give one molecule of Carbon Dioxide, one molecule of Calcium Chloride, and one molecule of water. You will now find that the total number of atoms on the left equals the total number of atoms on the right.

A chemical equation will indicate the weights of the reacting substances and the weights of the products of the reaction.

Referring to the table of atomic weights on p. 120 we get :—

$$CaCO_3 \quad + \quad 2HCl \quad \rightarrow \quad CaCl_2 \quad + \quad CO_2 \quad + \quad H_2O$$

$$\underbrace{\underbrace{40+12+(3\times 16)}_{100},\ \underbrace{2(1+35\cdot5)}_{73}}_{173} \rightarrow \underbrace{\underbrace{40+(2\times 35\cdot5)}_{111}+\underbrace{12+(2\times 16)}_{44}+\underbrace{(2\times 1)+16}_{18}}_{173}$$

This is in accordance with the Law of Conservation of Mass.

From the above it is obvious that 100 tons of Calcium Carbonate will react with 73 tons of Hydrogen Chloride to produce 111 tons of Calcium Chloride, 44 tons of Carbon Dioxide, and 18 tons of water.

Before attempting to write a chemical equation, it is essential to know the reacting substances and the products. Never

try to write a chemical equation in order to determine the products of a reaction.

Chemical equations do not tell us any of the conditions of the reaction. From the equation alone we do not know whether the above reaction takes place at low or high temperatures, we do not know whether to use dilute or concentrated acid, nor do we know whether or not there will be a precipitate. Such facts can be discovered by experiment, the equation simply enables us to calculate the weights of the reacting substances and of the products formed.

QUESTIONS

1. Give the formulæ of the following: Sodium Carbonate, Lead Nitrate, Ferric Sulphate, Zinc Hydroxide, Cupric Nitrate, Potassium Bicarbonate, Aluminium Sulphate, Calcium Bicarbonate, Ferrous Chloride, Magnesium Carbonate.

2. Write the equations for the following reactions:—

(*a*) Zinc added to dilute Sulphuric Acid gives Hydrogen and Zinc Sulphate.

(*b*) Carbon Dioxide passed into lime-water gives a precipitate of Calcium Carbonate.

(*c*) Carbon Dioxide passed for a long time into lime-water gives a clear solution of Calcium Bicarbonate.

(*d*) If a clear solution of Calcium Bicarbonate is boiled, Carbon Dioxide is evolved and Calcium Carbonate is precipitated.

(*e*) Hydrogen passed over heated Copper Oxide gives copper and steam.

3. What weight of Zinc Sulphate could be produced by completely dissolving 130 grm. of zinc in dilute Sulphuric Acid?

4. How many tons of copper can be displaced from excess of Copper Sulphate solution by 8 tons of iron?

5. What volume of Hydrogen at N.T.P. can be obtained by the action of 2 grm. of Magnesium on Hydrochloric Acid? (11·2 litres of Hydrogen at N.T.P. weigh 1 grm.)

6. How much Calcium Carbonate must react with Hydrochloric Acid to produce 5·6 litres of Carbon Dioxide at N.T.P.? (11·2 litres of Carbon Dioxide weigh 22 grm.)

CHAPTER XIV

CARBON, WOOD CHARCOAL, DISTILLATION OF WOOD

It is hard to think that the brilliant diamond, prized for its hardness and its lustre, and valued for so long as a precious stone, is the same chemical substance as soot, charcoal, and coal, and even as the graphite of the "lead" pencil with which you write. Chemical elements which have the power of existing in different physical forms and possessing totally different physical qualities are said to possess the property of **allotropy**. Carbon is a most striking example of a chemical element having allotropic modifications. Diamond and graphite bear very slight resemblance so far as colour, hardness, relative density, etc., are concerned, but when they are burnt in oxygen all give the same relative weight of Carbon Dioxide, thereby proving their identity.

Examine as many forms of Carbon as you can and report on their physical properties.

Graphite is found in nature in lumps, or nodules, in granite and other crystalline rocks. The best graphite for the purpose of making "black-lead" pencils was that formerly found exclusively at Borrowdale, in Cumberland, in the green slate rock. The mines have not been worked for nearly three-quarters of a century, but in the sixteenth and seventeenth centuries they were so productive as to yield an annual revenue of £40,000, although they were only worked a few weeks in the year for fear of exhausting the mines.

Graphite is found in Germany, Austria, the United States, Ceylon, and Southern Siberia. It can also be made artificially by melting cast iron containing a large proportion of Carbon and allowing it to cool slowly, when the graphite separates out.

Graphite has a peculiar soft, soapy feel and will mark paper easily. It has a relative density of 2·0–2·6, depending on the degree of purity of the natural product. It is a good conductor of heat and electricity, whilst diamond is a non-conductor.

Graphite burns in air at a temperature 600°–700° C. and forms Carbon Dioxide. It is used for a great variety of purposes. "Lead" pencils, first made at Keswick, in Cumberland (so called because at first graphite was confused with the metal lead), used to consist of pure graphite. Nowadays powdered graphite is mixed with carefully washed clay, and the mixture is placed in short iron cylinders having an opening at the bottom. The semi-solid mass is then pressed through the hole and the fine thread so obtained is used for pencil-making. Another important use of graphite is as a lubricant, its soft soap-like nature reducing friction between metallic surfaces. It is also used to make crucibles for metallurgical work, especially the manufacture of cast steel, and it finds a domestic use in "black lead" used for polishing iron grates and kitchen ranges. In the latter process the graphite is applied as a fine powder in suspension in water. The ironwork is then polished with a dry brush, and the thin coating of graphite protects the metal so that it does not rust.

Other Varieties of Carbon

(*a*) **Lamp-black**—This is formed when any oil is allowed to burn in an insufficient supply of air. You have probably noticed it on a lamp glass when an oil-lamp flame is turned too high. When purified it is used to make indian ink and also in calico printing. Common lamp-black is used as a black paint and for manufacturing printer's ink.

(*b*) **Gas Carbon**—This is formed in the preparation of coal-gas. It is found as a deposit in the upper portion of the retort (see p. 135) in the form of an iron-grey mass. It is often so hard that it strikes fire with steel like a flint does. Its relative density is 2·35. Gas carbon is a good conductor of heat and electricity, and is employed for Carbon plates in batteries and for Carbon poles in the electric arc.

(*c*) **Wood Charcoal**—Logs of wood are stacked as shown in fig. 127, and the stack is covered with earth or sods so that it will burn slowly in an insufficient supply of air. The relative density of wood charcoal when the pores are full of air varies between 0·1 and 0·2, according to the kind of wood originally used. Such charcoal will float on water, but if weighted and then boiled in water bubbles of air escape, and the pores become filled with water. When this is the case the relative density is greater than that of water, but never more than 2·0. In countries where wood is scarce, charcoal is made from small wood or sawdust by a process similar to that used in the distillation of wood, p. 129. By this process not only is the charcoal obtained, but also the volatile products, especially wood spirit and tar, which in the older process are allowed to escape into the air. Wood charcoal has a wonderful power of absorbing gases. It finds a use in filter beds, where it sweetens the water which may contain gases from decaying vegetable matter. It is also used in gas masks to absorb poison gases.

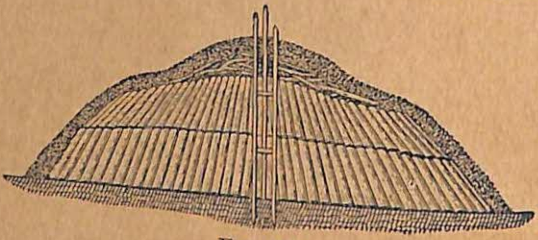

Fig. 127.

(*d*) **Animal charcoal** is a very impure form of Carbon, containing only about 10 per cent. of the pure element. It is made by charring bones. Its chief use is as a decoloriser. You can test this property easily by boiling a little litmus solution with animal charcoal. In a few moments the colour of the litmus has completely disappeared. Commercially it is used to decolorise the juice of raw sugar.

(*e*) **Coke**—This form of Carbon is obtained as a by-product in the manufacture of coal-gas. It is left behind in the retorts. It is also specially manufactured in coke ovens as it is a very important form of fuel, and there is much demand for it. The amount of coke produced in the gasworks of Great Britain in 1931 was about 11½ million tons. Coke burns at a much higher temperature than ordinary coal and gives no smoke. If steam is passed over red-hot coke a mixture of two combustible gases is formed, which is called water-gas. This important gaseous fuel is dealt with in the next chapter:

Difference between Burning Wood in Air and Heating it in Absence of Air.

(*a*) Put some small pieces of wood on a piece of gauze and heat over a Bunsen flame.

(*b*) Put about the same amount of wood in a crucible and cover with sand. Heat the crucible strongly for about ten minutes.

Allow to cool and examine the residue from the wood in each case. Describe carefully what you see.

Which form of Carbon have you made?

Distillation of Wood

You have observed that when wood is heated in absence of air a black substance—wood charcoal—is left. Let us try to collect some of the products which escaped when the wood was heated in the crucible.

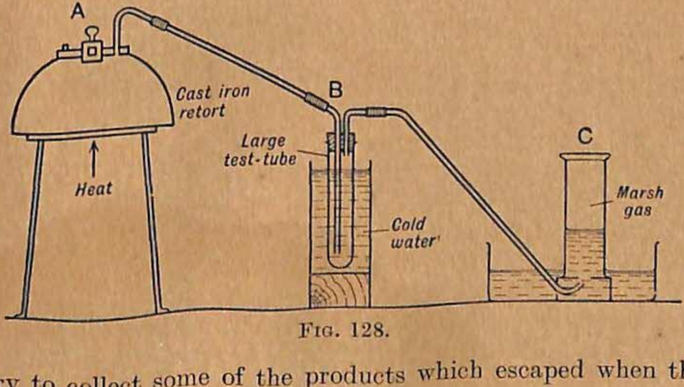

FIG. 128.

The apparatus used is shown in fig. 128. Small pieces of wood about 1 cu. in. in size are packed into the retort (A) and heated for about three hours. Large quantities of a gas can be collected at C, and about 60 c.c. of a tarry liquid collect in the boiling tube B. If this liquid is tested with litmus paper it gives an acid reaction. The gas which is collected at C is **marsh-gas** or **methane**. Apply a light to the mouth of a jar full of the gas. *Is the gas inflammable?* Test the gas left in the jar with lime-water. *What is it?* It can be shown when the dry gas is burnt at a jet that water is also formed. Thus

Marsh-gas burnt in air ⟶ Water + Carbon Dioxide.

Examination of the Tarry Liquid collected in the Boiling Tube

We have already shown that there is an acid in this liquid. We shall "fix" this acid by adding a base (lime), and so form a salt. After adding the lime the pasty liquid is distilled. The distillation flask (A) (fig. 129) is placed in a water-bath and the temperature kept about 60°–65° C. A little liquid collects in the receiver B. This liquid is inflammable. It is a mixture of two liquids, acetone and methyl alcohol (wood spirit). Owing to the ease with which wood spirit burns, it is used as a fuel.

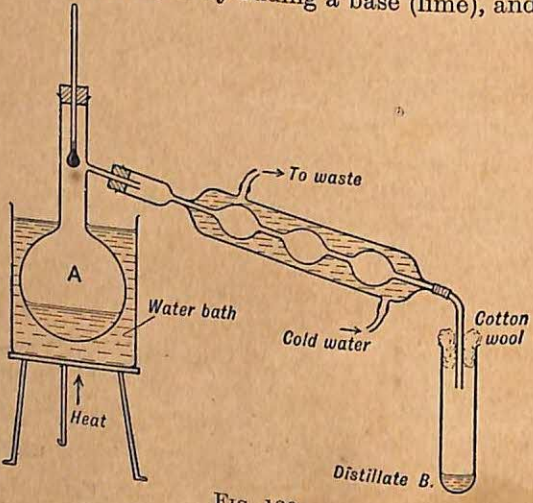

FIG. 129.

QUESTIONS

1. Explain the term "allotropy." Illustrate by reference to Carbon.

2. How would you distinguish between graphite and wood charcoal, and how would you endeavour to show that they are the same chemical substance?

3. Distinguish between "burning" and "distilling" wood. Contrast the products in the two cases.

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CHAPTER XV

COAL, DISTILLATION OF COAL, COAL-GAS, WATER-GAS, CARBON MONOXIDE

WHEN vegetable matter decays in the earth in the absence of air it undergoes a change similar to that which occurs when it is heated. Water, Carbon Dioxide, and marsh-gas are evolved, and the material becomes richer in Carbon. Marsh-gas and Carbon Dioxide are often held in the carbonised vegetable matter under great pressure, and their release during coal-mining is a source of grave danger. Marsh-gas in the mine is known as "fire-damp," and is explosive.

The coal seams, which occur in various thicknesses and at various depths in this country and elsewhere, have been produced by this decay of vegetable matter, which throughout the ages has been submitted to great pressure.

The illustrations will give you some idea of modern coal-mining and how machines are now used to replace much of the manual labour of former days.

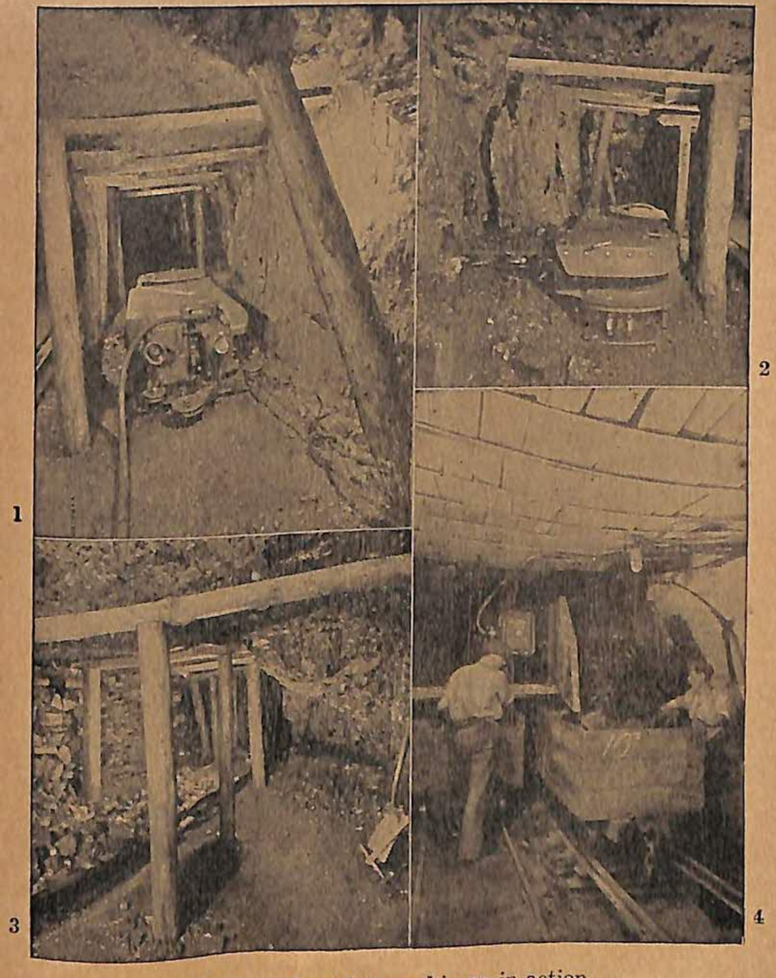
Difference between Burning Coal in Air and Heating it in Absence of Air

(*a*) Burn a small piece of coal on wire gauze so that it gets a plentiful supply of air. Examine the residue left after burning.

(*b*) Put some small pieces of coal in a crucible and cover with sand. Heat for about 10–15 minutes. Allow to cool, and tap out the contents of the crucible. The light spongy product is **coke**, and is very different from the **cinder** you obtained in experiment (*a*).

A Miniature Gasworks

Fit up the apparatus shown in fig. 130. An 8″ pyrex tube is filled about one-third full with small pieces (not powder) of



Modern coal-getting machinery in action

1. Electrically driven coal cutter, which is drawing itself along the coal face, its rapidly rotating drills tearing into the coal and making its removal easy.
2. Mechanical miner. Laborious hand-picking is being displaced by this remarkable type of machine. A large block of coal has been undercut and is ready to fall.
3. Mechanical conveyor. The coal is seen in the conveyor on the left of the picture.
4. Tub-filling by machinery.

coal. It is heated by means of a Bunsen burner, and it is better to start the heating at the right and proceed towards the left. This enables any gases to get away easily. The gases and vapours, which distil on heating the coal in this manner, are passed first through water, then through U-tubes to condense any vapours that become liquids at ordinary temperatures. They are then washed and passed over hydrated Ferric Oxide (a pale brown compound of iron which absorbs certain sulphur compounds), and the "coal-gas" is finally collected in a gas jar over water.

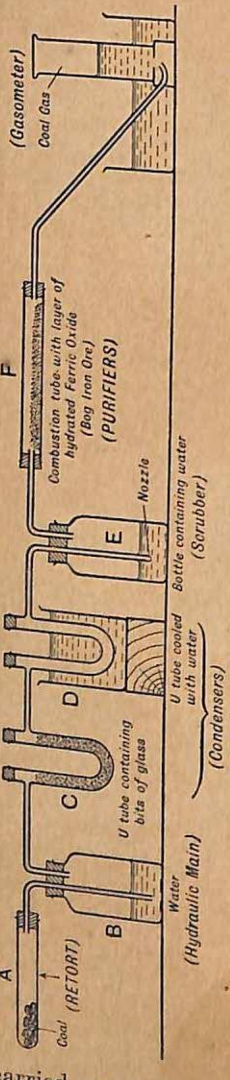

(Gasometer)
Coal Gas
F
Combustion tube with layer of hydrated Ferric Oxide (Bog Iron Ore)
(PURIFIERS)
Nozzle
E
Bottle containing water (Scrubber)
D
U tube cooled with water
(Condensers)
C
U tube containing bits of glass
B
Water (Hydraulic Main)
A
(RETORT)
Coal

FIG. 130.—A miniature gasworks

You can observe certain things of importance, although a full understanding of all the changes which have taken place will not be easy until a later stage. If the "water" in the bottle A is boiled with Caustic Soda, Ammonia gas is given off. You will no doubt recognise tar, which collects in B and also in the U-tubes C and D. The brown oxide of iron has gone black—it has been changed into the sulphide of iron—and you will note a different smell if you treat a little of the original oxide and the final product separately with dilute Hydrochloric Acid.

You will have collected quite a large quantity (about three ordinary sized jars full) of coal-gas, which you can light quite safely if you apply the light as soon as you remove the greased plate. You have, in fact, carried out the manufacture of coal-gas on a small scale.

If you pay a visit to your nearest gasworks you will see the process you have carried out in the laboratory being performed on a large scale. You will see several long retorts, made of fireclay and shaped somewhat as shown in fig. 131, arranged in one furnace bed. Each of these retorts holds about $4\frac{1}{4}$ cwt. of coal and is charged every eight hours. Fig. 132 shows the appearance of a retort house. Note the long semi-cylindrical scoop with which the coal is "fed" into one of the retorts. The gases are led off from each retort and are passed into hydraulic mains. It is here that much of the alkaline gas Ammonia is dissolved and some of the tar condensed. In the gasworks you will probably next be taken to the pump-house, for it is necessary to draw the gas out of the retorts and force it on the rest of its journey. The gas next passes through a series of condensers (fig. 133), where it is slowly cooled to get rid of most of the tar. Tar is a very

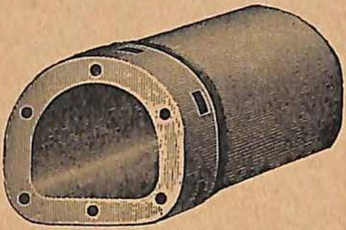


Fig. 131.

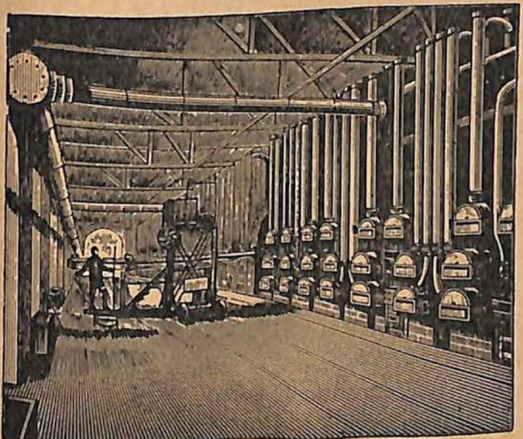


Fig. 132.

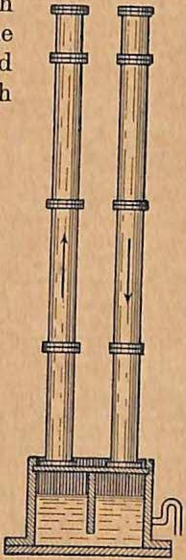


Fig. 133.

difficult substance to remove, and the final traces have to be washed out in a specially designed washer or scrubber. The Livesey Washer uses the principle that the smaller the bubble which is allowed to pass through water, the more effective is the washing. This removes the tar and the last traces of the very soluble gas Ammonia. The gas is caused to pass through perforated plates of wrought iron, with holes one-twentieth of an inch in diameter placed so that there are about thirty in a square inch of plate. It might be thought that such small holes would get made up with tar or other matter, but it is found that after years of use the plates are quite clean.

You will notice how very much more elaborate is the washing process than that which you performed in the laboratory. Of course it is much more necessary, because millions of cubic feet of gas are concerned. Each one of the perforations in the plates of the Livesey Washer does the same work as the nozzle of the glass tube in E (fig. 130).

After being thoroughly scrubbed the gas passes over hydrated Ferric Oxide in purifiers. In some works the gas is passed over lime as well as Ferric Oxide. The purifiers remove the objectionable sulphur compounds, Sulphuretted Hydrogen, Carbon Disulphide (and Sulphur Dioxide if lime also is used). If these gases, Sulphuretted Hydrogen and Carbon Disulphide, were allowed to contaminate the coal-gas, as they are both inflammable in air, they would burn in the coal-gas flame, producing Sulphur Dioxide, which would soon make the air of a room unbreathable. Gas companies are compelled by law to remove these sulphur compounds.

After passing through the purifiers the coal-gas is stored in large cylindrical tanks called gasometers.

You will begin to see of what enormous value coal is, and what an important part it plays in a country's commerce. Not only does it provide us with a gas that can light our streets, heat our houses, cook our meals, but in recent years a process has been tried with success to produce petrol from coal.[1] Also during the distillation of coal valuable by-products are obtained. Coke is left in the retorts and its uses have already been referred to; Ammonia liquor is caught in the hydraulic main and it is used as a source of Sulphate of Ammonia, a valuable fertiliser; tar is drawn off from various parts of the plant and is an extraordinarily valuable product. From tar some 200 distinct substances have been separated—a wonderful example of fractional distillation. There are in commerce to-day more than 2000 compounds which owe their origin to coal-tar. The following tables will repay study, and will show you the wonderful value of coal distillation:—

---

[1] A product resembling petroleum can be made by heating coal-tar with Hydrogen at a temperature of 430° C. This process is known as hydrogenation, and, if successful, should prove of great value to this country.

TABLE I

100 tons Coal

Flue dust	Graphite	Coke	Gas	Ammoniacal liquor	Tar
·05 ton	·1 ton	70 tons	21·55 tons (1,313,000 cu. ft.)	·29 ton Ammonia	5·32 tons (1000 gallons)

TABLE II

TAR

1000 gallons (5·32 tons)

Hard pitch, soft pitch	Anthracene oil	Heavy oil	Middle oils	Light oils	Prepared tar (road spraying)
75 cwt. (used in making waterproof paper, tarred felt, lamp-black, paving material, road tar)	used for Photo-dyes and Antiseptics	9¼ cwt. from which we get Creosote oil used for Sheep dip, lubricating oils, pickling timber	from which we get Naphthalene and Carbolic acid	Benzol	
			Middle and Light oils yield a large range of dyestuffs		

In addition, a very large range of scents and fine chemicals used in medicine owe their origin to tar.

Coal-gas

It is hard for us to imagine, accustomed as we are to the glare of its now many and varied illuminated signs, that London was lighted by gas for the first time in 1812, a little over a century ago.

Coal-gas consists of a mixture of gases, the proportions of which vary according to the nature of the coal carbonised. The chief constituents are Hydrogen, Methane or marsh-gas, Carbon Monoxide, and Ethylene—all of which burn in air. The following table shows the approximate amounts of the chief gases present in coal-gas from a bituminous coal:—

Hydrogen . . .	50 per cent.
Methane . . .	33 ,,
Carbon Monoxide . .	13 ,,
Ethylene . . .	4 ,,

Hydrogen, Methane, and Carbon Monoxide all burn with non-luminous flames. The luminosity of the ordinary gas burner depends upon the Ethylene present. In these days it is the heating power that is important and not the luminosity, for whenever gas is used as an illuminant the hot Bunsen flame brings a gas mantle to incandescence.

It is now customary to mix coal-gas with water-gas, a cheap form of fuel of high calorific value but with no illuminating power.

The Products of Combustion of Coal-gas

Use a small flame of a Bunsen burner and arrange the apparatus shown in fig. 134. Before lighting the gas draw some through the funnel and the lime-water to see if there is any change. Then light the gas and draw the products of combustion through the funnel and then through lime-water. Water will be found on the surface of the funnel (which should be dried before the experiment) and the lime-water will indicate the presence of Carbon Dioxide. The products of combustion of coal-gas are water and Carbon Dioxide

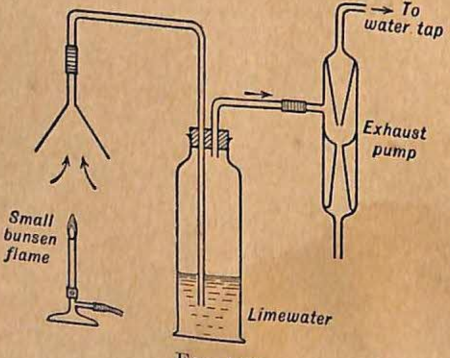


FIG. 134.

If the inner cone of a Bunsen flame be "broken," there is an escape of Carbon Monoxide. This gas is extremely poisonous, and its escape into the air is dangerous. Care must be taken, when using the gas rings on the gas cooker, that the little Bunsen flames are not "broken" by any utensil that is being heated. In most recent burners this difficulty is overcome by using "Rado burners" (fig. 135). These throw the flames out sideways, thus minimising the danger of "breaking" the cones.

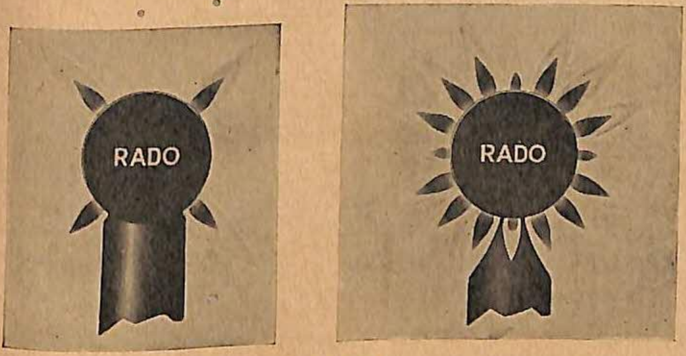


FIG. 135.

To Show the Liberation of Carbon Monoxide when the Flame is "Broken."

Fit up the apparatus shown in fig. 136. Two pieces of wire-gauze are supported on a ring $\frac{1}{2}$–$\frac{3}{4}$ in. above the top of the burner, so that the inner cone of the flame is broken by the gauze. Some Iodine Pentoxide is placed in a porcelain boat, B, contained in a glass tube, which is heated in an air-bath[1] with a sheet of asbestos card in the bottom to diffuse the heat. The temperature of the air-bath is maintained at about 160° C. The Carbon Monoxide liberated from the flame removes the Oxygen from the Iodine Pentoxide and sets Iodine free. The Iodine vaporises and is drawn through a solution of Potassium Iodide by means of a filter pump.

---

[1] Rowntree's gum or pastille tin, or Lyons' chocolate-biscuit tin, $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in. × 2 in. serves well for this.

A distinct colour change occurs in the Potassium Iodide solution as the Iodine dissolves in it.

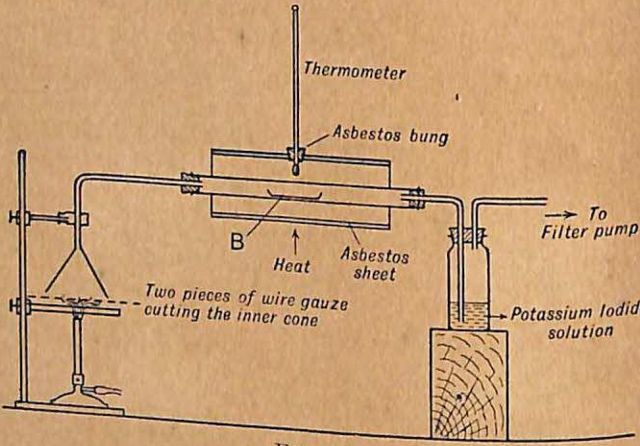
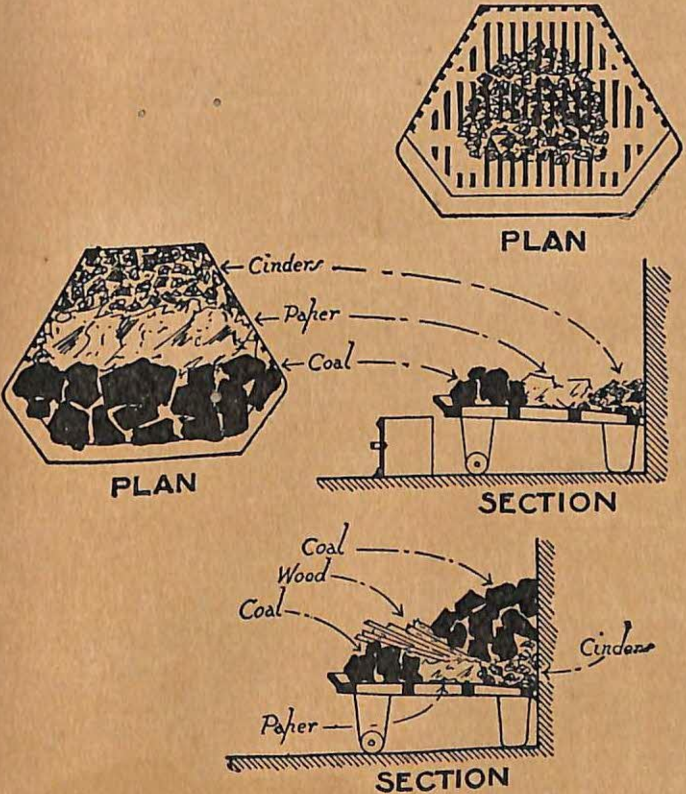

Thermometer
Asbestos bung
B
Heat
Asbestos sheet
→ To Filter pump
Two pieces of wire gauze cutting the inner cone
Potassium Iodide solution

FIG. 136.

Laying and Lighting a Household Fire

Often household fires are so badly laid that they have to be lighted several times before they will burn. A little thought about the process of combustion will help you to see how best to lay a fire (fig. 137). You make use of the fact that a match-head when rubbed on a prepared surface takes fire, so low is its ignition point that the heat produced by the friction of the match-head on the prepared surface is sufficient to raise it to its ignition temperature. The heat of the burning match will set fire to paper provided there is sufficient air to aid combustion. The temperature reached is now considerably higher than that of the thin match stick, and soon the wood sticks begin to crackle. You have seen that wood contains inflammable substances which are driven out by heat. These take fire, and flames result, which are sufficiently hot to release the inflammable gases in coal. The coal in turn burns, and emits the cheery blaze of the wasteful but much-beloved coal fire.

When Carbon burns in air or Oxygen, Carbon Dioxide is formed, and this gas does not burn, but escapes up the chimney. And yet, particularly over a coke fire, which reaches a higher temperature than a coal fire, you often see a blue flame. An experiment will show that part of the Carbon Dioxide which is formed in the lower part of the fire is changed by the red-hot carbon of the coal or coke into another gas which is inflammable. This gas is Carbon Monoxide.



[*By courtesy of Messrs. Bratt, Colbran & Co., and The Heaped Fire Co., Ltd.*

Fig. 137.

Preparation of Carbon Monoxide from Carbon Dioxide

A *slow* stream of Carbon Dioxide is passed through a long tube of red-hot carbon (fig. 138). The products of combustion are led through a series of bottles containing Caustic Potash to dissolve any unchanged Carbon Dioxide. The gas is finally collected over water.

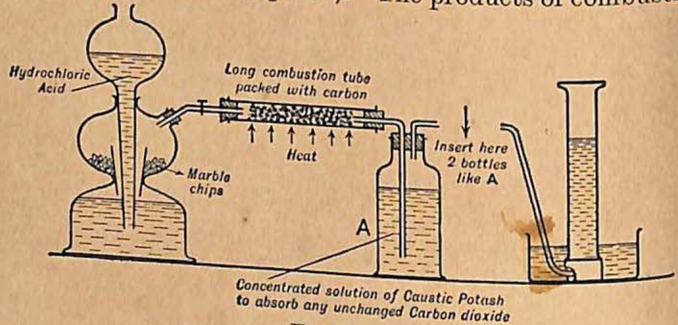

Hydrochloric Acid
Long combustion tube packed with carbon
Heat
Marble chips
Insert here 2 bottles like A
A
Concentrated solution of Caustic Potash to absorb any unchanged Carbon dioxide

FIG. 138.

Experiments to Show the Properties of Carbon Monoxide

(*a*) Test the gas with lime-water to see that it is free from Carbon Dioxide.

(*b*) Apply a light to the gas and note the blue flame. Now test the gas left in the jar for Carbon Dioxide. *What is formed when Carbon Monoxide burns in air?*

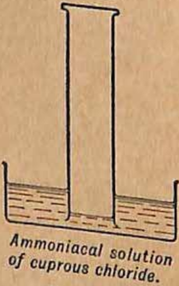


FIG. 139.

(*c*) Dissolve some Cuprous Chloride in Ammonia and invert a jar of the gas in it to find out if the gas will dissolve in this solution (fig. 139).

Carbon Monoxide is a very poisonous gas, and care must be taken not to breathe it. It is this gas which makes the exhaust gases of a motor-car so poisonous.

(*d*) Pass a stream of Carbon Monoxide over heated Lead Oxide (red lead) or heated Copper Oxide and note the changes that take place. The Carbon Monoxide has been changed into Carbon Dioxide and the metallic oxide reduced to the metal.

Carbon Monoxide is a powerful reducing agent, and may be used to extract metals from their naturally occurring oxides.

Water-gas

A silica tube (fig. 140) is filled with coke and placed in a furnace (or heated with several Bunsen burners). Two tubes pass through the cork A, and they are connected with an Oxygen cylinder and a steam generator. At the end B a delivery tube passes under water in a pneumatic trough so that any gas evolved may be collected. Disconnect the steam generator and remove the gas jar from the beehive shelf. While the water in the steam generator is being brought to the boil the silica tube is heated strongly and Oxygen passed gently over. This raises the coke to incandescence. When this state is reached shut off the Oxygen supply and connect the steam generator to the silica tube. After a few seconds replace the gas jar and collect the gas formed when the steam is passed over the incandescent coke.

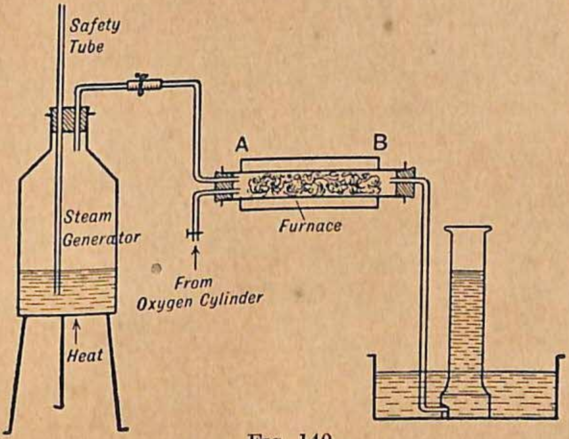


FIG. 140.

Set fire to a jar of the gas and test the gas remaining in the jar for Carbon Dioxide.

Allow a jar of the gas to stand for some time inverted in a dish which contains Ammoniacal Cuprous Chloride. When the solution has ceased to rise in the jar apply a light to the residue and again test for Carbon Dioxide. If the gas has been in contact with the Ammoniacal Cuprous Chloride for a sufficiently long time no Carbon Dioxide should result on burning the residual gas. This gas is Hydrogen. Water-gas is composed of a mixture of Carbon Monoxide and Hydrogen.

$$\underset{\text{(Hydrogen Oxide)}}{\text{Steam}} + \underset{\text{(Carbon)}}{\text{Coke}} \longrightarrow \underset{\substack{\text{(Carbon Monoxide}\\ \text{+ Hydrogen)}}}{\text{Water-gas}}$$

Water-gas prepared in this way is known as "blue" water-gas. Before water-gas is mixed with coal-gas it is subjected to a process known as **carburetting**, and the resulting gas is called **carburetted water-gas.** "Carburetting" is thoroughly mixing "blue" water-gas with gasified oil.

It is interesting to note that the calorific value of "blue" water-gas is 300 B.Th.U., while that of the "carburetted" water-gas is 400 B.Th.U.

The manufacture of carburetted water-gas as an illuminating agent has until comparatively recently been confined to the United States and Canada, where its manufacture is almost as extensive as that of coal-gas. Its manufacture is now quite widespread in this country, and a plant is found in practically every gasworks.

To Measure the Heat of Combustion (Calorific Value) of Coal with a Fuel Calorimeter.

One of the simplest forms of apparatus for determining the heats of combustion of solid, liquid, and gaseous fuels is Darling's fuel calorimeter (fig. 141).

In finding the heat of combustion of coal a gram of powdered coal is weighed into a nickel crucible, C, which is held in position in the glass or copper bell jar, B, by springs.

B is flanged and supported by a brass plate, E, which rests on three legs, L. A steady stream of Oxygen is passed through *O* and then the calorimeter is lowered into a measured quantity of water in the large glass jar, F. Ignition is started by passing an electric current through a platinum spiral which dips into the fuel.

The hot gases pass down D and bubble through a series of small holes in the plate P. The temperature rise is determined by a thermometer reading in tenths of a degree. The water equivalent of the calorimeter is supplied with the apparatus, and a determination is quickly made.

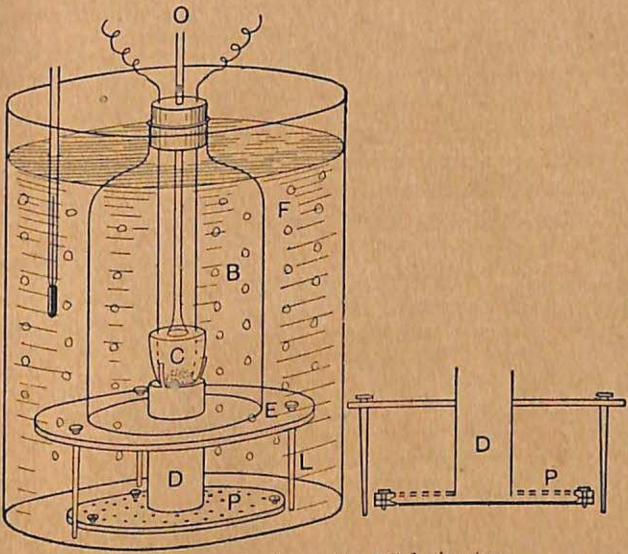


FIG. 141.—Darling's Fuel Calorimeter

Results

Sample :—1 grm. of Welsh Steam Coal.

Initial temperature of water = 12·1° C.
Final temperature of water = 17·3° C.
∴ Rise in temperature = 5·2° C.
Mass of water taken = 1400 grm.
Water equivalent of apparatus = 230 ,,
Heat gained = (1400 + 230) 5·2 = 8476 calories.

Calculate the calorific value in B.Th.U. per lb.

QUESTIONS

1. Give a general description of the manufacture of coal-gas, and give some account of the more valuable by-products.
2. Describe a Bunsen flame. What are the products of combustion of coal-gas? How is it that Carbon Monoxide is sometimes found in these products of combustion? Describe an experiment to verify this.
3. How should a household fire be laid? Why is it necessary to have a good draught?
4. How would you prepare a fairly pure sample of Carbon Monoxide? What are its principal properties?
5. What is water-gas? How is it made? What is it used for?
6. Describe by means of a diagram a Davy safety-lamp for use in coal-mines or in the neighbourhood of a supply of petrol.
7. The following substances are generally regarded as dangerous. Explain what chemical or physical properties cause this danger. State what precautions are necessary for the safe use or storage of these substances:—phosphorus, sodium, concentrated sulphuric acid, petrol, coal-gas.
8. Describe fully with diagrams how you would show that a gas is given off when a little bicarbonate of soda is heated in a test-tube, and how would you identify the gas?

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CHAPTER XVI

NITROGEN, NITRIC ACID, NITRATES, AMMONIA

You have already learnt that the gas which occupies approximately 80 per cent. by volume of the earth's atmosphere is called Nitrogen. It is a colourless gas, without taste or smell, almost insoluble in water, and without action on litmus. It does not support combustion nor does it burn. And yet this gaseous element plays a very important part in plant and animal life. Leguminous plants can take up atmospheric Nitrogen, which is converted into organic Nitrogen compounds by the agency of bacteroids which occur in nodules on the root. These organic Nitrogen compounds in plants serve as food for herbivorous animals, which in turn provide proteins for the carnivora.

So important a part does Nitrogen play in plant life that a great demand is made on the Nitrogen compounds present in the soil. There is an almost inexhaustible supply of Nitrogen in the earth's atmosphere, and the problem which faced the chemist was how to fix this Nitrogen in compounds which plants could assimilate, and so provide an essential food for plants other than the leguminosæ.

You have already learnt that the Nitrogen can be separated from the Oxygen in the air by removing the Oxygen with burning phosphorus.

It is also possible to do this by passing air to and fro over heated copper.

Fit up the apparatus shown in fig. 142. The tube is packed with copper turnings and is heated in a furnace. By raising the cylinder C and opening taps T_1 and T_2 air can be forced slowly over the heated copper. When all the air in A has been forced over and the residue collected in B this residue can be forced back again by raising the cylinder D. This should be continued until there is no further reduction in volume.

Nitrogen has been obtained by passing air over heated copper. The copper is partially converted into Copper Oxide.

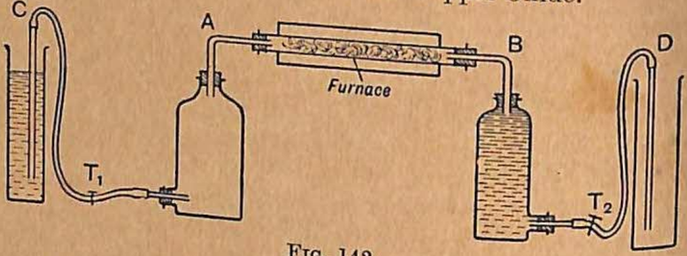

FIG. 142.

Both Nitrogen and Oxygen are obtained in large quantities from the air by a process of liquefaction and subsequent evaporation. If a gas under great pressure is forced through a jet and allowed to expand, cooling results. This fact is made use of in the liquefaction of air. Air freed from Carbon Dioxide and water vapour under a pressure of 200 atmospheres is cooled to room temperature, and then allowed to escape through a series of nozzles in the plug C (fig. 143). This process cools the compressed air before it escapes through the jet. Suppose the compressed air is cooled to − 45° C., after passing through the jet and expanding it is further cooled to, say, − 90° C. This process is repeated by pumping, and finally a temperature of about − 200° C. is reached. Liquid Nitrogen boils at a temperature of − 195·5° C. and liquid Oxygen boils at − 182·5° C. Thus the liquid air obtained by the above process is a mixture of two liquids of different boiling-points. Fractional distillation of the liquid air will therefore separate the Nitrogen and the Oxygen. The Nitrogen, possessing as it does the lower boiling-point, will distil over first. This method of manufacture requires only air and power, and therefore provides a cheap supply of both Nitrogen and Oxygen. The Oxygen is stored in cylinders under several atmospheres

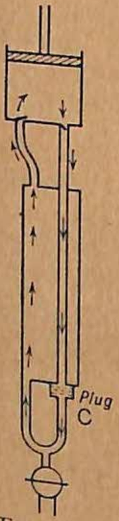

FIG. 143.—Linde-Hampson apparatus

pressure, and the only impurity in the gas is a very little Nitrogen (always less than 0·5 per cent. by volume).

How Nitrogen in the Air is Converted into Substances available for Plant Food

There are several ways in which this can be done and only the most important will be described in outline.

(*a*) Direct combination of the Nitrogen and Oxygen of the air, with the formation of Nitric Acid, which latter is allowed to react with limestone, forming Calcium Nitrate.

(*b*) Converting Nitrogen, obtained from air by the liquefaction process, into Ammonia—an alkaline gas from which can be made salts like Sulphate of Ammonia, Nitrate of Ammonia, both of which are valuable fertilisers.

(*c*) Oxidising Ammonia made as in (*b*), and thus forming Nitric Acid.

(*a*) The Formation of Nitric Acid from the Air

This method is used in countries where water-power is abundant, thus enabling a supply of electricity to be obtained cheaply.

A simple experiment can be performed which demonstrates the chemical changes taking place in the process.

Dry air contained in a glass globe is sparked for about an hour (fig. 144). A yellowish-brown gas is formed, which on shaking with water forms an acid solution. It can be shown that this solution contains Nitric Acid.

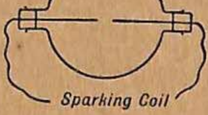

FIG. 144.

In the manufacturing process an electric arc is spread out by a powerful electromagnet into an apparent disc of flame. Air is passed through, and at the temperature of the arc (about 2000° C.) about one per cent. of the Nitrogen is converted into Nitric Oxide, which is a colourless gas. This very hot gas goes into a large tower where it is slowly oxidised to the reddish-brown gas, Nitrogen Peroxide. This is the coloured gas you noticed in the previous experiment. The Nitrogen Peroxide is next forced up large granite towers packed with stone, down which water trickles. Nitric Acid is formed, and may be neutralised with limestone to form Calcium Nitrate,

$$\underset{\text{Nitrogen Peroxide}}{3NO_2 + H_2O} \longrightarrow \underset{\text{Nitric Acid}}{2HNO_3} + \underset{\text{Nitric Oxide}}{NO},$$

$$2HNO_3 + \underset{\text{limestone}}{CaCO_3} \longrightarrow \underset{\text{Calcium Nitrate}}{Ca(NO_3)_2} + H_2O + CO_2.$$

(*b*) The Direct Combination of Hydrogen and Nitrogen

The direct combination of Nitrogen and Hydrogen by sparking a mixture of the two gases in a eudiometer tube is difficult to show because Ammonia gas is also decomposed into Nitrogen and Hydrogen when it is sparked. We have, in fact, a reversible reaction,

$$2NH_3 \rightleftharpoons N_2 + 3H_2,$$

and no further change takes place when 6 per cent. of Ammonia and 94 per cent. of the mixed gases, Nitrogen and Hydrogen, are present in the mixture. If, however, the Ammonia is removed as soon as it is formed, then the combination of Nitrogen and Hydrogen continues. Use is made of the fact that Ammonia is an alkaline gas, and thus is rapidly absorbed by dilute Sulphuric Acid.

The mixture of Hydrogen and Nitrogen is sparked in a tube standing in dilute Sulphuric Acid. The volume of the gases slowly diminishes and Sulphate of Ammonia is formed.

On the large scale use is often made of substances which help chemical reactions, which in themselves are slow, to be quickened up to such an extent as to make the manufacture pay. Such substances are called **catalysts.**

A simple experiment will enable you to observe one example of catalytic action.

Heat separate portions of Potassium Chlorate and of Manganese Dioxide in hard glass test-tubes. Note how difficult it is to obtain samples of Oxygen gas,

$$2KClO_3 \longrightarrow 2KCl + 3O_2.$$

The decomposition of Potassium Chlorate into Potassium

Chloride and Oxygen requires a very high temperature. It requires a still higher temperature to obtain any Oxygen from Manganese Dioxide.

Now make a mixture of the two by powdering together about 5 grm. of Potassium Chlorate and 1 grm. of Manganese Dioxide. On heating, Oxygen is evolved much more rapidly and at a much lower temperature.

When no more gas is evolved, boil the residue with water. This dissolves the Potassium Chloride but not the Manganese Dioxide. Filter through a filter paper (which was weighed after drying at 100° C.), being careful to get all the Manganese Dioxide on the filter paper. Wash the residue thoroughly with distilled water, dry in the water-oven, and weigh. You should be able to show that there is the same weight of Manganese Dioxide at the end as there was at the beginning.

Nowadays very great use is made of catalysis in chemical industry.

In the direct combination of Nitrogen and Hydrogen by the Haber process (1905), a mixture of very pure Hydrogen and Nitrogen, in the correct proportions and under a pressure of about 200 atmospheres, is passed over a heated catalyst consisting of iron with some other material, called a **promotor.** The Ammonia formed may be liquefied or dissolved in water. It is then easy to convert it into one of the salts, in which form it will be available as a plant food.

(c) Oxidation of Ammonia

Owing to the importance of Nitrates for soil fertilisers, the cheap manufacture of Nitric Acid is always eagerly sought. You have noted one method (p. 149), and the preparation of synthetic Ammonia has provided us with another one.

Fit up the apparatus shown in fig. 145. Oxygen is blown into a strong solution of Ammonia, and a mixture of Oxygen and Ammonia fills the flask. Now heat the platinum spiral by passing a current of electricity through it. A feeble explosion results, and then the glowing wire causes the Oxygen to oxidise the ammonia, and red gaseous Nitrogen Peroxide and white fumes of Ammonium Nitrate are formed.

On the large scale Ammonia gas mixed with air is passed over heated platinum gauze, which acts as the catalyst, and Nitric Oxide is produced,

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O.$$

The colourless Nitric Oxide is easily oxidised to the red Nitrogen Peroxide by the excess of Oxygen,

$$2NO + O_2 \longrightarrow 2NO_2,$$

and this dissolved in water yields Nitric Acid.

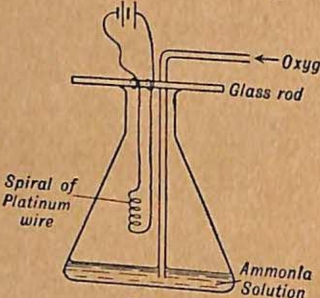

Fig. 145.

Laboratory Method of Preparation of Ammonia, and Experiments to Illustrate its Properties

I. Heat separately small quantities of horn, hoof, hair, and feathers in small test-tubes. Note the evolution of an alkaline gas which gives white fumes with Hydrochloric Acid.

Ammonia is formed by the decomposition of nitrogeneous animal matter either by heating, as in the above experiment, or during slow decay. The presence of Ammonia may always be detected in the atmosphere of a stable.

II. Fit up the apparatus shown in fig. 146. A mixture of slaked lime and sal ammoniac (Ammonium Chloride) is heated in a large test-tube, the mouth of which is inclined slightly downwards. If required dry, the gas must be passed through a tower or U-tube containing lumps of quicklime (or soda lime). *Neither Calcium Chloride nor Sulphuric Acid can be used to dry the gas, as it combines with both these substances.* As the gas is lighter than air (density = 8·5, air = 14·6), it is collected by passing the gas upwards and displacing the air downwards. Small quantities of the gas can be collected in dry test-tubes (fig. 146A), and for many of the experiments this method will prove quite satisfactory.

Perform the following experiments, and make a careful record of your observations and conclusions in each case:—

(*a*) Allow a test-tube full of the gas to stand mouth downwards in a beaker of water.

(*b*) Bring a rod dipped in Hydrochloric Acid near the mouth of a test-tube full of the gas.

(*c*) Note the effect of the gas on litmus.

(*d*) Find out if the gas burns.

(*e*) Find out if the gas allows a lighted match to burn in it.

(*f*) Note the colour and smell.

(*g*) Make a solution of the gas in water, using a funnel as a safety-valve.

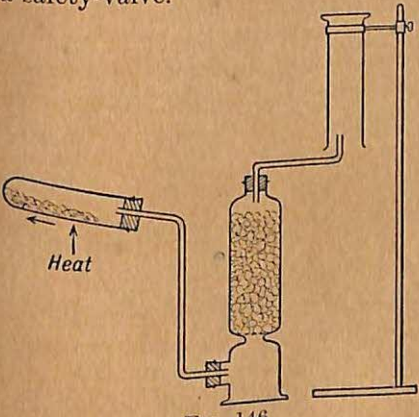

FIG. 146.

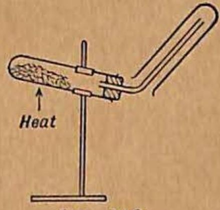

FIG. 146A.

Experiments with a Solution of Ammonia in Water

Note the effect of adding Ammonia solution to aqueous solutions of the following :—

(*a*) Copper Sulphate.
(*b*) Ferric Chloride.
(*c*) Ferrous Sulphate.
(*d*) Aluminium Sulphate.

Use of Ammonia Solution in Removing Grease Stains

Shake a little oil with water and allow to stand. Note what happens. Compare the effect of shaking the oil with a solution of Ammonia.

When an oil is broken up into little tiny drops, so small that they do not separate easily but are held in suspension, the mixture is called an emulsion.

Alkalies have the effect of making emulsification take place more readily. It is for this reason that washing soda is added to water in which greasy utensils are to be washed.

The cleansing action of soap is largely due to the same process. When soap dissolves in water a little Caustic Soda is set free which emulsifies any grease which may be present. As, however, Caustic Soda has a rotting effect on such materials as silk and wool, it is wiser to wash these in soap lather rather than use a piece of bar soap.

Grease stains may be removed from materials by rubbing with an alkali which does not rot the material. It is here that Ammonia solution is so useful, as it removes the grease without damaging the material. When an alkali has emulsified grease, both are removed together by rinsing in clean soft water.

Refrigerators

In modern refrigerating plants, such as are used for cold storage on ships and for domestic purposes, a low temperature is produced by the rapid evaporation of liquid ammonia.

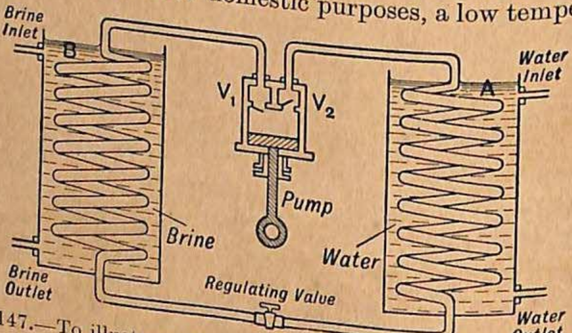

FIG. 147.—To illustrate the principle of an ammonia refrigerating plant

Ammonia may be liquefied at ordinary temperatures by pressure alone, about ten atmospheres or 155 lb. wt. per sq. in. being necessary at 22° C.

The **principle** of the method may be understood by reference to fig. 147, which shows the simplest form of ammonia refrigerating plant. The pump, run by a steam-engine or by an electric motor, compresses the ammonia gas into the coils A and liquefies it. The latent heat released is removed by the circulating water. The liquid ammonia passes slowly through the regulating valve into the coils B, where the pressure is kept low by the pump drawing vapour through valve V_1. In B the liquid rapidly boils, the latent heat necessary being taken from the brine surrounding the coils. The brine, the temperature of which falls several degrees below 0° C., is circulated round the storage rooms, where it keeps the temperature below 0° C. In hot countries theatres and hotels are cooled by forcing air directly over the coils B, and in this case the brine is dispensed with.

QUESTIONS

1. Explain the importance of Nitrogen in plant life. How does the plant obtain this important element?
2. How has the chemist "fixed" the Nitrogen of the air in a form that would be available for plants?
3. Describe the process of liquefaction of air. How may Nitric Acid be obtained from the Nitrogen of the air?
4. What do you mean by a catalyst? Describe any experiment which illustrates catalytic action.
5. How is Ammonia gas prepared in the laboratory? What is its action on (*a*) litmus, (*b*) Sulphuric Acid, (*c*) a solution of Copper Sulphate, (*d*) grease?

CHAPTER XVII

ESSENTIAL ELEMENTS OF FOOD AND FOOD-STUFFS

A NUMBER of elements are essential for the life of an animal or plant. These are obtained from food, and it has been found that they must be present in food in the form of definite compounds termed food-stuffs.

The classes of essential food-stuffs are: Carbohydrates, Proteins, Fats; Inorganic Salts, Vitamins, and Water are also needed. Green plants are able to make the other food-stuffs from Carbon Dioxide, water, and inorganic salts. Animals need the food-stuffs to be present ready-made in food.

(A) **Carbohydrates** are complex compounds containing Carbon, Hydrogen, and Oxygen, the atoms of the last two elements being present in the ratio 2 : 1. The chief Carbohydrates in food are starches, sugars, and celluloses.

(i) *Starch* $(C_6H_{10}O_5)_n$ is present as ovoid or spherical concentrically marked grains in cereals, potatoes, and leguminous seeds. It is insoluble in cold water, but forms an opalescent solution on boiling. It gives a blue colour with iodine solution. It is converted into sugar by dilute mineral acids or by the action of certain substances termed ferments (enzymes),

$$(C_6H_{10}O_5)_n + nH_2O \rightarrow nC_6H_{12}O_6 \text{ (glucose, a sugar).}$$

Boil starch with water, allow to cool. An opalescent solution is formed, which sets to a jelly on cooling.

Treat a solution of starch in water as follows: (*a*) Add Iodine solution—a blue colour is produced. (*b*) Add a few drops of 25 per cent. Sulphuric Acid. Boil. Cool. Add a few drops of Fehling's solution. Boil. A yellow-red precipitate of Cuprous Oxide is produced. This shows the presence of glucose. (*c*) Add a little saliva, stir for some minutes, and test for glucose.

(ii) *Sugars* are sweet crystalline compounds soluble in water. The most important are *Cane-sugar*, $C_{12}H_{22}O_{11}$, and *Glucose*, $C_6H_{12}O_6$. The former is present in sugar-cane, the latter in many fruits, *e.g.* grapes. Similar sugars are present in honey and milk. *Cane-sugar* does not react with Fehling's solution, but it gives a red colour when boiled with concentrated Hydrochloric Acid.

(iii) *Celluloses* are colourless solids found, *e.g.*, in the cell-walls of green plants. They are insoluble in water and are not easily digested by most animals (see, however, Rabbit, p. 167). Cellulose (*e.g.* cotton-wool) gives a blue colour if acted upon by a few drops of strong Sulphuric Acid on the subsequent addition of Iodine solution.

Uses of Carbohydrates in Food

Carbohydrates contain much energy and are readily oxidised. The break-down products are Carbon Dioxide and water, and much energy is liberated.

The chief use of carbohydrates in the living organism is to supply energy as a result of oxidation, the process being termed internal respiration. All other carbohydrates are first converted into glucose, which is always the substance oxidised. The protoplasm of green plants also has the power of making proteins as a result of a series of reactions, the original reacting substances being glucose and nitrates.

(B) **Proteins** are extremely complex bodies containing Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, and often Phosphorus. They are an essential part of protoplasm, and no vital activities can take place in their absence. In the living body they are first broken down into simpler bodies, which are then built up by protoplasm to form new protoplasm. This is termed assimilation.

They are usually solids or viscous liquids, often insoluble in water, and coagulate on heating (*e.g.* white of egg). Typical proteins are egg-albumin (in egg-white), myosin (in lean meat), gluten (in flour), aleurone (in some leguminous seeds, *e.g.* beans, peas).

(i) To a little egg-white add strong Nitric Acid. A white coagulated mass is formed. Boil. It turns yellow. Cool. Add a little strong Ammonium Hydrate. It turns orange.

(ii) To a little egg-white add an equal volume of water, next a drop of Copper Sulphate solution, then a little Potassium Hydrate solution. A violet colour is produced.

(iii) To a little egg-white add a few drops of Millon's solution. Boil. A brick-red precipitate is produced.

Uses and Break-down Products of Proteins

Proteins are used in assimilation (see above). When protoplasm breaks down as a result of vital activity, a number of simpler nitrogenous compounds (nitrogenous waste products) are produced. In animals these are usually converted into urea (and uric acid) and excreted, usually in urine. In the higher plants the nitrogenous waste products are often retained in the plant protoplasm as insoluble, and therefore harmless, granules, oils, and pigments, the plant having no excretory organs.

(C) **Fats** are compounds of Carbon, Hydrogen, and Oxygen, containing only a little Oxygen. They are solid or liquid (oils) compounds of fatty acids with the base glycerin, are insoluble in water, soluble in ether, and make a greasy stain on paper. They are found in many animal tissues, and in some seeds (*e.g.* "linseed" of Flax). Boiling with caustic alkalies converts them into soaps. Shaken with water, liquid fats form a creamy fluid, the minute fat globules being in suspension (an emulsion, *e.g.* milk).

(i) Dissolve a little fat in ether. Place a drop on paper, allow the ether to evaporate. A greasy stain is left.

(ii) To a little fat add a few drops of one per cent. Osmic acid. It turns black.

Uses and Break-down Products of Fats

Fats are oxidised in the body, heat being evolved. The waste products are Carbon Dioxide and water.

Inorganic Salts—Saline solutions containing Calcium, Potassium, Sodium, Magnesium, Phosphorus, and Iron are needed by animals and plants for the purpose of tissue formation and of the substance made by tissue. Bone contains

Calcium Phosphate and Carbonate; red blood contains Iron, Potassium, Sodium, and Phosphorus; Chlorophyll contains Magnesium but no Iron—although it can be formed only in the presence of Iron. (See also reaction of sugar and nitrates above.)

Vitamins—although not strictly "food-stuffs"—must be present in food. They are complex substances, present only in minute quantities; their activity is stopped by boiling. Several of them have been isolated, but the exact composition of some of them is still unknown. All were originally made by green plants, although they are present not only in these but also in, *e.g.*, milk, butter, and cod-liver oil. There are at least five of them.

Vitamin A—Soluble in fat solvents and present in butter and cod-liver oil.

Vitamin B—Soluble in water. Present in wheat germ, rice, and yeast.

Vitamin C—Soluble in water. Present in fresh fruits, especially oranges and lemons.

Vitamin D—is usually found associated with Vitamin A. It is soluble in fats.

There are also two other vitamins, E and F, which have recently been isolated.

Their absence causes abnormal growth and certain diseases, for example, absence of Vitamin B may lead to beriberi, absence of Vitamin C will cause scurvy, and absence of Vitamin D is the cause of rickets. Hence the necessity that diet should include fruit and green vegetables.

CHAPTER XVIII

ANIMAL NUTRITION: NUTRITION IN THE MAMMAL

Introduction—In the Biology section of Part II we studied the structure of some simple animals and plants, and their life processes, *i.e.* how they obtain and use food, how they move, respire, excrete, and reproduce. In the present section we shall consider the structure and life processes of some higher animals and plants.

How Food is Used—We have already studied the chief *food-stuffs* (p. 156). They are the useful constituents of various substances used as food.

Food is used for two purposes within the body of an organism. It supplies *energy*, including *heat*, and it supplies substances which the living organism builds up into *protoplasm*. An organism needs energy because its active tissues expend energy. Some food-stuffs supply this energy. Active tissues also "wear away" and must be replaced. Growing organisms make additional tissue. New tissue, whether to replace waste or for growth, is made from certain food-stuffs which are built up into protoplasm.

Carbohydrates (p. 156) are the main source of energy. *Fats* (p. 158) supply heat. *Proteins* (p. 157), *salts*, and *water* are used in making protoplasm. **Respiration** is the process by which food sets free energy in the body of an organism. This will be studied in the next chapter. **Nutrition** includes the intake of food, and all the changes it undergoes in being converted into protoplasm. In this chapter we shall study the nutrition of those higher animals which are classed as

Mammals—A **Mammal** is a backboned animal (**Vertebrate**). Its young are born alive: they do not "hatch" from eggs. They are suckled by the mother, who produces milk for this purpose. The Mammal has two pairs of limbs, each with (usually) five digits, and its body is more or less clothed with hair.

Digestion is the first stage of nutrition. It takes place in the *alimentary canal*. We shall now consider this process in detail.

The Alimentary Canal (fig. 148).

Food taken in at the mouth passes into and along a tube called the *alimentary canal*, the other end of which opens at the hind end of the body. The opening is the *anus*. From the *mouth* onwards the parts of the alimentary canal are the "back of the mouth" (*pharynx*), the gullet (*œsophagus*), the *stomach*, and the gut (*intestine*). The whole of the canal, including the mouth cavity, is lined with a soft pink tissue

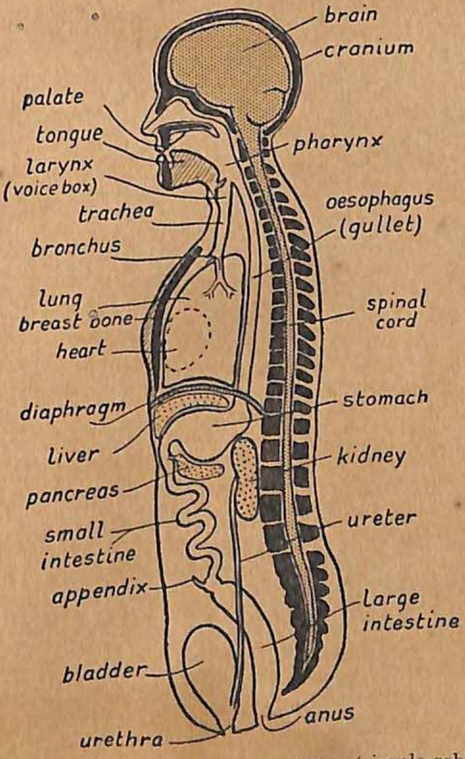

FIG. 148.—Chief internal organs of Man (simple scheme)

(*mucous membrane*), very rich in blood-vessels. The *mouth cavity* lies between the jaws. The *pharynx* and upper part of the gullet are in the neck. The remainder of the alimentary canal is within the body cavity. This extends from the root of the neck to the hind end of the body (*trunk*). A tough membrane called the *diaphragm* extends across the body cavity at the level of the lower (posterior) ribs. It divides the body cavity into a smaller anterior portion (*thorax*), and a larger posterior portion (*abdomen*). The greater part of the œsophagus lies in the thorax, but its lower end penetrates the diaphragm. The stomach and intestines lie in the abdomen. The general arrangement of the alimentary canal is shown—somewhat simplified—in figs. 148 and 149.

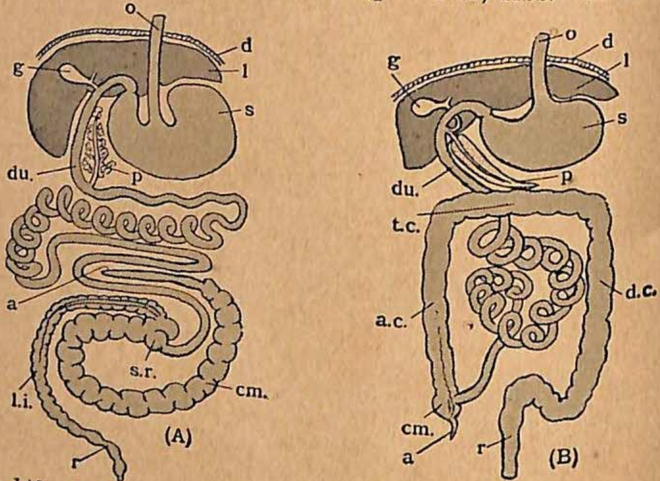

FIG. 149.—Diagram of alimentary canal of a Mammal (much simplified). (A) Rabbit; (B) Man

o = lower part of œsophagus, *d* = diaphragm, *s* = stomach, *g* = gall-bladder and bile-duct, *p* = pancreas and pancreatic duct, *l* = liver, *du* = duodenum, *li* = large intestine, *ac* = ascending colon, *tc* = transverse colon, *dc* = descending colon, *sr* = sacculus rotundus, *cm* = cæcum, *a* = vermiform appendix, *r* = rectum.

The *œsophagus* is a narrow muscular tube. The *stomach* is a large oval sac extending from left to right across the abdominal cavity immediately below the diaphragm. The *intestines* are suspended from the dorsal wall of the abdomen by folds of tough tissue (*mesentery*). The *small intestine* is very long (Man 22 ft. × 1 in., Rabbit 7 ft. × $\frac{1}{3}$ in.), and is much looped. Its first loop is called the *duodenum*. The *pancreas* ("sweetbread") lies in the duodenal loop. It discharges *pancreatic juice* by a *pancreatic duct* into the duodenum. The large red *liver* lies above and to the left of the stomach. The pear-shaped *gall-bladder* is attached to the lower surface of the liver. *Bile* made by the liver collects in the gall-bladder, and is discharged by the *bile-duct* into the duodenum. The lower end of the *small intestine* opens into the wider *large intestine* (about 5 ft. long in Man, 3 ft. in Rabbit). The posterior end (*rectum*) of the large intestine opens to the exterior by the *anus*. The *vermiform appendix* of Man is a small finger-shaped tube at the junction of the large and small intestines. In this position the Rabbit has a large sacculated tube, the *cæcum* ($1\frac{1}{2}$ ft. long, 1 in. wide), which ends in an appendix (4 in. long).

Wave-like contractions (Part II, p. 169) of the wall of the alimentary canal force the food along it.

Digestive juices are made by the *salivary glands* in the mouth, by cells lining numerous small pits (*gastric glands*, fig. 152) in the walls of the stomach, in the small intestine (*intestinal glands*, fig. 153), and by the liver and pancreas. These juices are poured out into the alimentary canal. They mix with the food and digest it as it passes along the canal. The walls of the small intestine absorb the soluble products of digestion. The undigested portions of the food are termed *fæces*. These are expelled at the anus.

Open the body of a Rabbit along the mid-ventral line. Remove the breast-bone and ventral parts of the ribs. Identify the organs shown in fig. 149. *Unravel the intestines. Sketch.*

Enzymes, and How They Act on Food-stuffs

Each digestive juice contains one or more soluble substances called ferments or *enzymes*. These digest food-stuffs. Each enzyme acts upon one class of food-stuff, and produces one soluble product, which can be absorbed by the walls of the intestine. Enzymes are present in *very small* quantities, but can act on large amounts of food. They act best at about 35–40° C., and are readily destroyed by heat. Each of them needs a liquid of a certain degree of acidity or alkalinity in which to act. (Compare these properties with those of *catalysts*.)

How Food is Digested in the Mouth

Food is chewed, and thus broken up into small fragments upon which the digestive juices can readily act. *Salivary glands* in the cheeks and below the tongue make *saliva*, and discharge it into the mouth. *Saliva* mixes with and moistens the food. *Ptyalin*, the enzyme of saliva, changes *starch* into *sugar*. This action begins in the mouth. It is completed in the stomach, into which the swallowed food quickly passes.

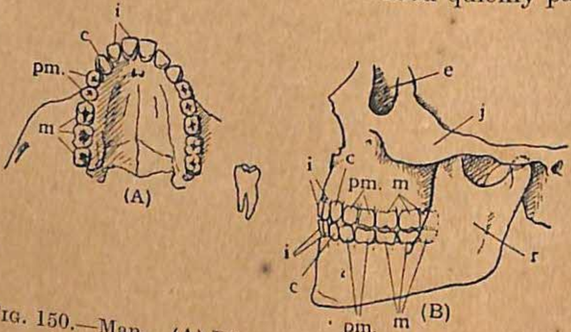

FIG. 150.—Man. (A) Diagram of upper jaw from below; (B) Diagram of jaws from left side
i = incisors, c = canine, pm = premolars, m = molars, r = ramus of lower jaw, j = cheek-bone, e = orbit.

Examine the teeth of Man and Rabbit.

Most Mammals have four kinds of teeth. The front teeth are chisel-shaped cutting teeth (*incisors*). Next to these are conical tearing teeth (*canines*), one in each side of the jaw. (Note that the *Rabbit has no canines*. As the Rabbit eats no fleshy food they are not needed. There is a long space between incisors and grinders). The back or "cheek" teeth are grinders and are divided into *premolars* and *molars*. Premolars are represented in the first or "milk" set of teeth, but molars are not. They are additional cheek teeth which appear only in the second or "permanent" set, and are behind the premolars.

$$\text{Man}\ \frac{\text{(Upper) i. 2, c. 1, pm. 2, m. 3}}{\text{(Lower) i. 2, c. 1, pm. 2, m. 3}}\ \text{on each side.}\quad \text{Total 32.}$$

$$\text{Rabbit}\ \frac{\text{i. 2, c. 0, pm. 3, m. 3}}{\text{i. 1, c. 0, pm. 2, m. 3}}\ \text{on each side.}\quad \text{Total 28.}$$

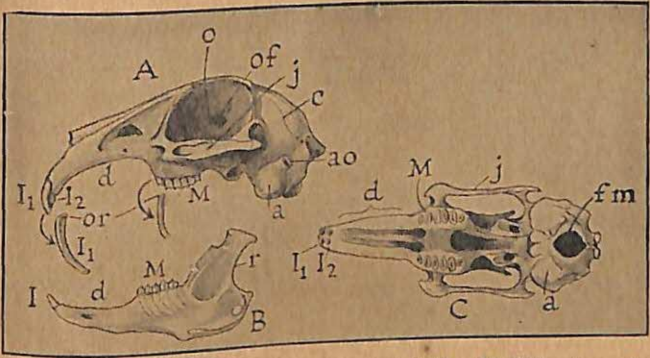

FIG. 151.—Rabbit. (A) Side view of skull; (B) Side view of left half of lower jaw; (C) Skull from below

I, I = 1st and 2nd incisors, *or* = open root, *d* = diastema, M = molars (upper with concave, lower with ridged crowns), *a* = auditory capsule, *ao* = auditory opening, *o* = orbit, *of* = optic foramen, *j* = jugal (cheek-bone), *c* = cranium, *r* = ramus of lower jaw, *fm* = foramen magnum.

How Food is Digested in the Stomach

Presence of food in the stomach acts as a stimulus. The *gastric glands* (fig. 152) respond by making and pouring out *gastric juice* into the stomach. The stomach performs churning movements which mix the food and the juice. Gastric juice contains two enzymes, and is acid owing to the presence of hydrochloric acid. The enzyme *pepsin* changes *proteins* into *soluble peptones*. *Rennin* curdles *milk*, which is thus more easily digested.

The acid mixture of partly digested food is called *chyme*. It contains undigested fats, some undigested carbohydrates (*e.g.*

starch), some undigested proteins, also peptones and sugar. After a time the ring of muscle at the junction of the stomach and the duodenum relaxes and allows the chyme to pass into the small intestine.

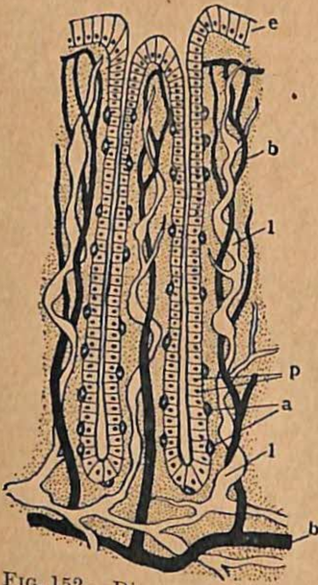

Fig. 152.—Diagram of a gastric gland from the cardiac end of the stomach

e = epithelium, *b* = blood capillaries, *l* = lymphatic, *a* = acid-forming cells, *p* = pepsin-forming cells. (Glands from the pyloric end of the stomach have pepsin-forming cells only.)

How Food is Digested in the Small Intestine

The presence of food in the small intestine causes the gall bladder to pour bile, and the pancreas to pour pancreatic juice into the duodenum. The intestinal glands also pour intestinal juice into the canal.

The digestion of all classes of food-stuffs is completed in the small intestine. *Bile* is a yellow alkaline liquid. It contains no enzyme, but aids the action of an enzyme (*steapsin*) in the alkaline pancreatic juice. This changes *fats* into *soap* and *glycerin*, which are absorbed by the wall of the intestine. Another enzyme (*amylopsin*) of the pancreatic juice changes *starch* into *sugar*. A third pancreatic enzyme (*trypsin*) changes *proteins* into *peptones*. The alkaline *intestinal juice* made by the *intestinal glands* (fig. 153) changes *peptones* into simple soluble substances called *amino-compounds*, which are absorbed by the walls of the canal. The undigested remains of the food pass out to the large intestine.

No Digestion takes place in the Large Intestine

Bacteria in the large intestine cause undigested food, especially any *cellulose* which may be present (*e.g.* from green vegetables), to decompose with the production of gases (*fermentation*).

The food of the Rabbit contains much cellulose. In the *cæcum* some of the *cellulose* is changed into *sugar* by the action of the *bacteria*. The walls of the cæcum absorb the sugar.

How Digested Food is Absorbed and Used

The lining of the small intestine bears a large number of small finger-like outgrowths called *villi* (fig. 153). They absorb the products of digestion (amino-compounds, sugar, glycerin, and soap). All of these finally enter the blood, and are carried to the tissues.

Sugar is used for the liberation of energy in the process of respiration (to be described later). *Soluble proteins* are assimilated, *i.e.* built up into new protoplasm. This repairs waste. It may also be used for growth. *Fat* is oxidised by the process of respiration, and heat is produced. Spare fat collects in fatty tissue in various parts of the body.

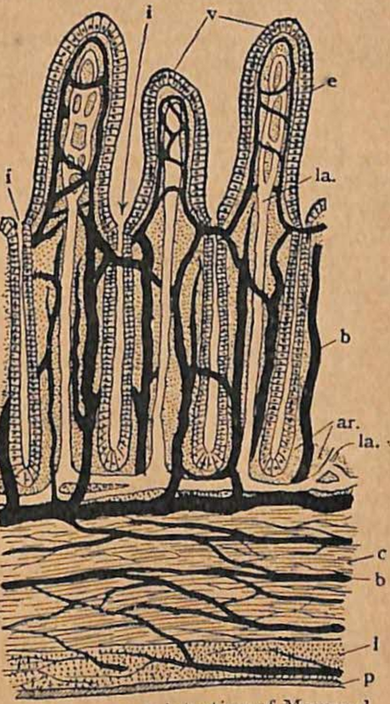

Fig. 153.—Small intestine of Mammal. Diagram of part of transverse section (highly magnified)

v = villus, i = intestinal gland, la = lacteal (lymphatic containing chyle), b = blood-vessel, ar = loose connective (areolar) tissue, e = columnar epithelium, c = layer of circularly disposed involuntary muscle fibres, l = layer of longitudinally disposed involuntary muscle fibres, p = peritoneal layer.

Each *villus* contains a network of small blood-vessels. These collect into veins, which leave the intestine and unite to form the *portal vein* (p. 180). This goes to the liver, and breaks up into a network of capillaries. These collect into a large *hepatic vein*, which leaves the liver and opens into a large vein (*posterior vena cava*), which enters the heart. Each villus also contains a vessel called a *lacteal*. The lacteals unite into a larger vessel (*thoracic duct*), which passes from the intestines, and opens into a large vein at the root of the neck.

Sugar (the product of digestion of carbohydrates) is absorbed into the blood-vessels of the villi, and is carried in the blood of the portal vein to the liver. Here it is changed into a starch-like substance (*glycogen*), which is stored in the liver cells until it is needed. Glycogen changes into sugar (*glucose*) when the tissues need it. The glucose is carried in the blood from the liver to the tissues all over the body.

Amino-compounds (the product of digestion of proteins) are absorbed and changed into the *soluble proteins* of the blood (*serum albumin, serum globulin*). These are carried as above, first to the liver, and then to the tissues.

Glycerin and soap (the products of digestion of fats) are absorbed by the villi, and recombine into little drops of *fat*. The fat passes into the lacteals. These also contain *lymph* (p. 176). The fat and lymph form a milky liquid called *chyle*. This passes by the thoracic duct to the veins near the heart. The blood carries the fats to the tissues.

Water and *mineral salts* only are absorbed by the walls of the large intestine. They pass into the blood of the portal vein, and so to the tissues.

QUESTIONS

1. Explain the purposes for which food is used in the body of an organism, carefully explaining how each class of digested food-stuff is absorbed and used.
2. Describe and sketch the alimentary canal and associated organs of a Mammal. Enumerate the chief differences between the alimentary canal of Man and that of the Rabbit.
3. Describe the processes of digestion in (*a*) the stomach, (*b*) the intestine.
4. Describe (*a*) a gastric gland, (*b*) a villus, and (*c*) the part played by the liver in the process of digestion.

CHAPTER XIX

ANIMAL RESPIRATION: RESPIRATION IN THE MAMMAL

Introduction—It has already been stated that the energy needed by a living organism is set free within the tissues. It is a result of the process of *internal or tissue respiration*, *i.e.* the oxidation of food-stuffs (mainly carbohydrates) by the action of oxygen. This oxygen is taken into the body and carried to the tissues. The waste products of internal respiration are carbon dioxide and water. They are removed from the tissues. The carbon dioxide and some of the water (in the form of water vapour) are got rid of from the body by the respiratory organs (lungs). *External respiration* includes the intake of oxygen, its supply to the tissues, and the removal and output of the carbon dioxide and water vapour.

Internal Respiration in the Animal Body

We have already seen that *carbohydrates* are changed into *glucose*, which is carried in solution by the blood to the tissues. In the tissues it is changed into *glycogen*—a body similar to starch. Glycogen, which contains much potential energy, breaks up into *lactic acid*, which contains less energy. *The energy set free is used by the tissues.* Thus the energy used by the animal was originally obtained from glucose in the blood.

The action is really somewhat more complicated than this, but the essential facts are as stated. Lactic acid must be removed from the tissues (see p. 170). Oxygen brought by the blood oxidises some of it into carbon dioxide and water. The blood carries away these waste products. The energy set free when some of the lactic acid is oxidised is used in changing the rest of the lactic acid into glycogen. This can again be used, and the whole process is repeated. The result of the whole series of reactions may be simply expressed as follows:—

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}.$$

Sometimes the oxygen used in the process of internal respiration is not taken in from the outside, but is obtained by the breakdown of the protoplasm of the organism. This is termed *anaerobic respiration*, and is exhibited by many bacteria, dormant seeds, and some parasitic animals.

How the Animal uses Energy

The energy set free in the tissues is used in performing various activities such as movement, secretion, and the assimilation of proteins to make new tissue. New tissue is needed either to replace tissue waste or for growth. Some heat also is produced, especially as a result of the oxidation of fats. This causes some animals, *e.g.* Birds and Mammals, in which there is much heat-production to be " warm-blooded." We shall see later that in such animals there is delicate adjustment of heat-production and heat-loss, which keeps their bodies at an even temperature.

How Fatigue is Caused

Much heat is produced when an animal is very active. Large amounts of energy have to be rapidly liberated. Much lactic acid collects in the tissues (*e.g.* in the active muscles). Unless quickly removed it causes the muscle to become fatigued and unable to work well. A rapid supply of oxygen is needed to oxidise, and therefore to remove the lactic acid. Hence the animal breathes more quickly and its blood circulates more rapidly until the lactic acid has been oxidised by the oxygen in the blood. The products of this action are carbon dioxide and water. They are carried away by the blood.

External Respiration in the Mammal

The Respiratory Organs—In **Mammals**, as in other air-breathing **Vertebrates** generally, the respiratory organs are a pair of *lungs*. These are a pair of oval elastic sacs covered with a moist shiny coat (*pleura*). They lie right and left of the heart, and with it occupy practically the whole of the thorax cavity. They are light in weight, pale greyish-pink in colour, and of spongy texture. Each lung is made up of thousands of fine air-tubes called *bronchioles* Each bronchiole ends in a group of small air-sacs (*alveoli*). The bronchioles of each lung unite and finally collect into a single large air-tube (*bronchus*), which leaves the top (anterior) end of the

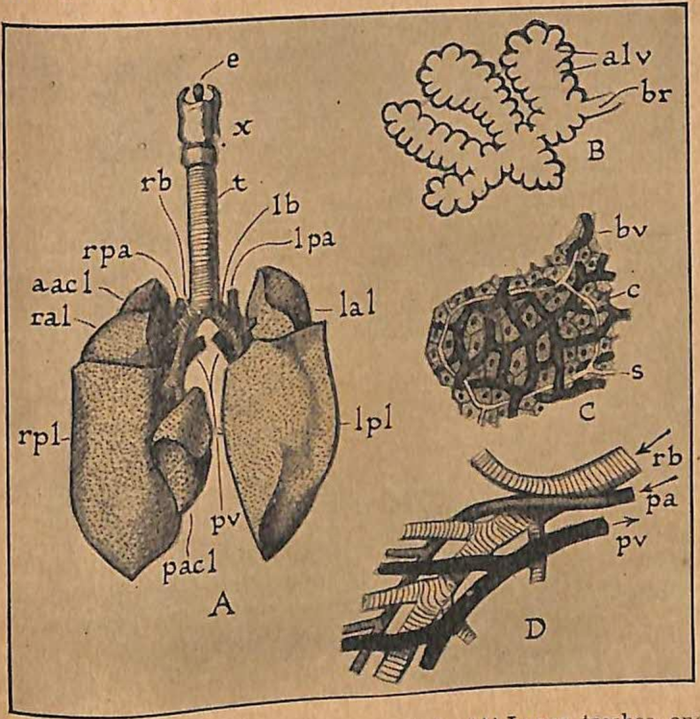

FIG. 154.—Lungs of Rabbit (diagrammatic). (A) Lungs, trachea, and bronchi; (B) Group of alveoli (air-sacs); (C) Wall of alveolus, showing epithelial cells and blood capillaries; (D) Arrangement of bronchial tubes and blood-vessels.

e = epiglottis, *x* = larynx, *t* = trachea, *rb*, *lb* = right and left bronchi, *rpa*, *lpa* = right and left pulmonary arteries, *pv* = pulmonary veins, *aacl* = anterior accessory lobe, *lal*, *ral* = left and right anterior lobes, *lpl*, *rpl* = left and right posterior lobes, *pacl* = posterior accessory lobe, *alv* = alveolus, *br* = bronchiole, *bv* = blood capillary, *c* = epithelial cell, *s* = septum.

lung. The right and left bronchi unite, forming the windpipe (*trachea*), which runs up the neck immediately ventral to the gullet. The top of the trachea forms a cylindrical cartilaginous voice-box (*larynx*, "Adam's apple"), which opens by a small opening (*glottis*) in the floor of the *pharynx*.

A large artery (*pulmonary artery*) enters the top of each lung, and divides into many small branches, which run beside the bronchioles. The smallest arteries break up into a network of *capillaries* on the walls of the air-sacs. These capillaries unite into small veins, which finally collect into a large *pulmonary vein* which leaves the top of the lung. A thin layer of elastic connective tissue lies between the bronchioles, air-sacs, blood-vessels, and pleura. The walls of the trachea, bronchi, and larger bronchioles contain a number of incomplete rings of cartilage. These rings prevent the tubes collapsing, and so cutting off the supply of air to the air-sacs.

Examine the lungs of a Rabbit. Note the larynx, trachea, bronchi: also the blood-vessels entering or leaving the lungs. After death the lungs are collapsed (see fig. 154). Pass the nozzle of a pipette into the larynx.

Blow air into the lungs. They are inflated. Remove the pipette. Note the elastic recoil of the lungs.

Cut a small cube of lung tissue and place it in water. It floats. *Squeeze it under water.* Small air-bubbles come out. This shows that the elastic recoil has not expelled all the air from the lung.

Cut open a lung. Note the edges of the numerous bronchioles and blood-vessels. In order to see the air-sacs (alveoli) and capillaries, a prepared section of lung tissue should be examined under the microscope.

How the Mammal Breathes

Air is drawn into the lungs and expelled from them by *breathing movements*. A complete cycle of breathing movements consists of an *inspiration*, a brief *pause*, and an *expiration*.

Note the breathing movements of a Rabbit, Cat, or Dog. Note also the movements of your own ribs and breast-bone during inspiration and expiration. Count your respirations per minute when (*a*) sitting, (*b*) walking.

The walls of the thorax contain a number of *ribs*, the dorsal ends of which are movably jointed to the backbone. There are twelve pairs of ribs in Man (and Rabbit). The ribs curve in a posterior and ventral direction from the sides of the backbone. The first ten pairs of ribs in Man (first nine in the Rabbit) are united by cartilage to the breast-bone, which lies in the mid-ventral wall of the thorax.

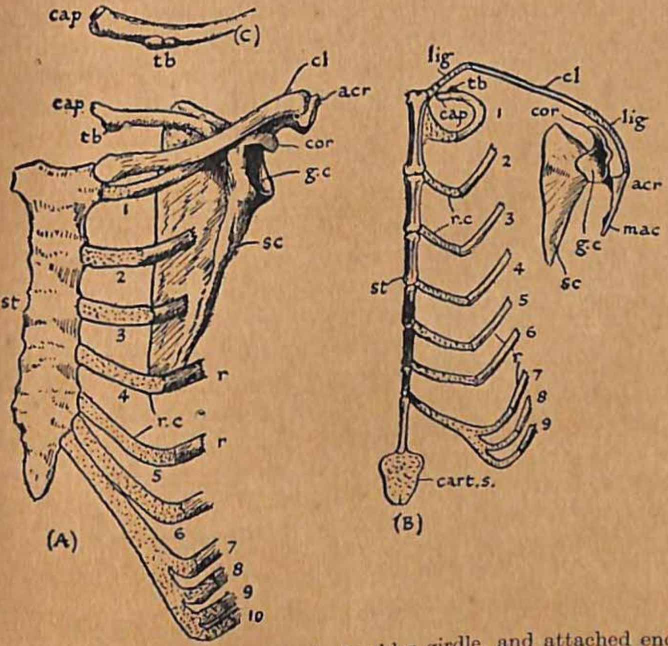

FIG. 155.—Breast-bone (sternum), shoulder girdle, and attached ends of ribs of (A) Man, (B) Rabbit. (C) Rib of Man, dorsal view (head and tubercle)

acr = acromion (process of scapula), *cap* = capitulum (articulates with centra of two vertebræ), *cl* = clavicle, *cart.s* = cartilage flap of sternum, *cor* = coracoid process of scapula, *gc* = glenoid cup, *mac* = metacromion, *lig* = ligament, *r* = rib, *rc* = rib cartilage, *st* = sternum (note separate bones in sternum of Rabbit, *tb* = tubercle (articulates with transverse process of vertebra), *sc* = scapula.

Muscles between the ribs connect them to the spine. These *intercostal muscles* are used in breathing movements.

Inspiration—The *external intercostal muscles* contract, causing the ribs to pivot against the backbone. The ribs move outwards, and in a ventral and anterior direction. The breast-bone is pushed " forward," *i.e.* in a ventral and anterior direction. This increases the front to back (dorso-ventral) and side-to-side diameters of the thorax. At the same time the diaphragm contracts and "flattens." This increases the head to tail (antero-posterior) diameter of the thorax. The air pressure in the lungs (which equals the atmospheric pressure) causes the elastic lungs to expand and fill the whole thorax cavity. The expansion of the lungs causes the air pressure within them to fall below the atmospheric pressure outside. Air immediately flows into the lungs until the pressure within and without are equal. *This inflow of air is inspiration.*

Expiration—After a short pause the external intercostal muscles and diaphragm relax. The ribs pivot posteriorly and dorsally, the breast-bone "sinks in," and the middle of the diaphragm "domes" upwards, *i.e.* in an anterior direction. These movements diminish the capacity of the thorax cavity. The pressure of the ribs, breast-bone, and diaphragm upon the lungs compresses them. The air pressure within the lungs therefore rises above the atmospheric pressure outside. Air is immediately expelled from the lungs until the pressure within and without are equal. *This output of air is expiration.*

How Respiratory Gases are Exchanged in the Lungs

The pulmonary artery brings blood to the lungs. This blood contains carbon dioxide and water. These it received from the tissues in which internal respiration takes place. The blood has also lost some of its oxygen, which it has given up to the tissues. The walls of the capillaries in the lungs are very thin, and permit gases to pass through them. The blood gives up some of its carbon dioxide and water vapour to the air in the air-sacs. It receives oxygen in exchange. The oxygenated blood then leaves the lung by way of the pulmonary vein, and carries this oxygen to the tissues in all parts of the body.

As a result of this exchange of gases between the air and the blood in the lungs, the air loses about 5 per cent. of oxygen to the blood and receives 4·5 per cent. of carbon dioxide and a variable amount of water vapour from the blood.

How the blood carries oxygen and carbon dioxide will be considered in a later chapter (pp. 177, 178).

QUESTIONS

1. Describe the process of internal respiration in the animal body. Explain its purpose.
2. Describe and sketch the respiratory organs of a Mammal.
3. Describe the breathing movements of a Mammal.
4. Explain what takes place in the lung of a Mammal during the process of respiration.

CHAPTER XX

THE CIRCULATORY SYSTEM AND THE BLOOD OF THE MAMMAL

THE CIRCULATORY FLUIDS AND THE CIRCULATORY SYSTEM

THE tissues of an animal need a constant supply of dissolved food and oxygen. The waste products of tissue activity must also be removed from the tissues. These two duties are carried out by two fluids which circulate through all parts of the body. The fluids are BLOOD and LYMPH. Blood circulates through a continuous system of *blood-vessels*, which are connected with a central pumping organ, the *heart*. *Arteries* carry blood from the heart. They branch repeatedly, and form a complicated system of very fine vessels called *capillaries*. These penetrate between the cells of all living tissues. Capillaries unite into larger vessels called *veins* which return blood to the heart.

Lymph is a fluid which is really a part of the blood that ha oozed through the walls of the capillaries. It bathes al tissues, and collects into a system of vessels called *lymphatics* The largest lymphatics return lymph into the blood. They open into two large veins at the root of the neck, so that the lymph mixes with the blood returning to the heart.

The Structure of the Blood

Blood is a sticky, slightly alkaline liquid. It consists of a nearly colourless liquid termed *plasma*, in which float myriads of small masses of protoplasm called *corpuscles*. They are of two kinds, *red corpuscles* and *colourless corpuscles*. The former greatly outnumber the latter, hence blood has a red colour.

The *red corpuscles of Mammals* (Rabbit, Man) are minute, circular, biconcave discs with rounded edges (fig. 156). They are non-nucleated, and their protoplasm contains a red iron-containing protein pigment called *hæmoglobin.* The pigment readily absorbs oxygen, and holds it in loose chemical combination, forming *oxyhæmoglobin.* This has a scarlet colour, hence the bright scarlet tint of oxygenated (arterial) blood.

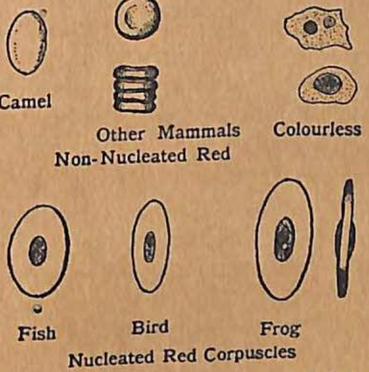

Fig. 156.—Blood corpuscles of Vertebrates (highly magnified)

It readily gives up oxygen to the tissues, and absorbs carbon dioxide from them. The hæmoglobin then has a purple colour, well seen in deoxygenated (venous) blood.

Colourless corpuscles are rounded masses of protoplasm, each with one or more nuclei (fig. 156). They perform amœboid movements.

Blood platelets, much smaller amœboid colourless bodies, also float in the plasma. A cubic millimetre of human blood may contain about five millions of red corpuscles, ten thousand colourless corpuscles, and half a million blood platelets.

To show the Alkaline Reaction of Blood—Draw a drop of blood from the finger. With it moisten a piece of red litmus paper. After 20 secs. wash the paper with distilled water. The blood stains the paper blue.

To show the changes undergone by Hæmoglobin when exposed to (a) *Oxygen, and* (b) *Carbon Dioxide*—Bubble oxygen through freshly drawn blood in a test-tube. It turns scarlet. Bubble carbon dioxide through it. As the oxygen is expelled and carbon dioxide is absorbed, the blood turns purple.

The Functions of Blood

(a) *Blood and the Process of Respiration*—Blood carries *oxygen* from the lungs to the living tissues, and carries *carbon dioxide* from the tissues to the lungs. Oxygen enters the blood from the air in the air-cells. The walls of the air-cells and of the capillaries are so thin that oxygen passes through them from the air into the blood, and carbon dioxide passes from the blood into the air. When the blood reaches the tissues, the thin walls of the capillaries allow lymph to pass from the blood to the tissues. **Lymph** is plasma with some colourless corpuscles. *It is the carrier between the blood and the tissues, i.e.* it carries oxygen to, and carbon dioxide from, the tissues.

(b) *Blood and the Carriage of Dissolved Food*—*Glucose*, *amino-compounds*, and *salts*, absorbed by the capillaries of the walls of the intestine, are carried to the liver in the blood of the *portal vein*. They pass from the liver to the heart, and then by the arteries and capillaries to the tissues. *Lymph carries them to the tissue cells.*

Fats absorbed by the lacteals also reach the blood (p. 168), and are similarly given up to the tissues.

(c) *Blood and the Removal of Waste Matter from the Tissues*—In addition to carbon dioxide produced as a result of tissue respiration, there are other waste products which are formed in the tissues. The protoplasm of active tissue breaks down into a number of *nitrogenous waste substances*. These are carried away by the lymph, and poured into the blood. When the blood passes through the liver, the liver cells change these waste substances into *urea*. Sooner or later the blood passes through the kidneys, which remove urea, waste water, and salts from the blood (see p. 184). This mixture is the fluid termed *urine*.

(d) *Blood and the Carriage of Chemical Messengers*—In certain parts of the body there are formed minute amounts of substances called *hormones* (chemical messengers). These are carried by the blood to certain other parts of the body, which are roused by them and caused to carry on certain activities.

Let us consider an instance of this: One of the hormones is a substance called *secretin*. When food enters the duodenum, the walls of the latter are stimulated and make secretin. This is carried away by the blood of the capillaries in the walls. The blood carries secretin to the *pancreas*, which becomes active. It pours *pancreatic juice* into the intestine. The juice then digests the food in the intestine.

(e) *Blood and the Distribution of Heat*—Tissue respiration liberates heat in the tissues (p. 169). The blood flowing through active tissues is warmed. It flows all over the body, gives up heat to the tissues, and so keeps the body warm. Most of the heat of the body is produced in the muscles and the liver (see also p. 170).

(f) *Blood and Defence against Disease*—Many diseases are produced by minute colourless unicellular plants called *bacteria*. Harmful bacteria enter the body and produce poisons called *toxins*. The blood makes substances called *antitoxins*, which kill the bacteria and neutralise the effect of the toxins. Colourless corpuscles also "eat up" the bacteria. Thus the blood defends the body against attacks by harmful bacteria.

(g) *Blood and the Formation of Clots*—Blood flowing from a wound clots and thus prevents death from loss of blood. The blood plasma contains a soluble protein called *fibrinogen*. The colourless corpuscles in the blood flowing from a wound make a ferment called *fibrin ferment*. The ferment and fibrinogen react, and form a sticky network of threads of an insoluble protein called *fibrin*. Red corpuscles are entangled in this network, and a jelly-like *blood clot* is formed. The clot plugs the wound and the bleeding is stopped.

THE HEART AND THE CIRCULATION OF THE BLOOD

The heart is a hollow organ with thick muscular walls. It is made up of four chambers. These are a *right* and a *left auricle* above, and a *right* and a *left ventricle* below. In the floor of each auricle there is an opening by which the auricle communicates with the ventricle of the same side. The openings are guarded by *valves*. A valve is a flap of tissue which will allow blood to flow in one direction, *e.g.* from the auricle into the ventricle, but will not allow any flow in the opposite direction.

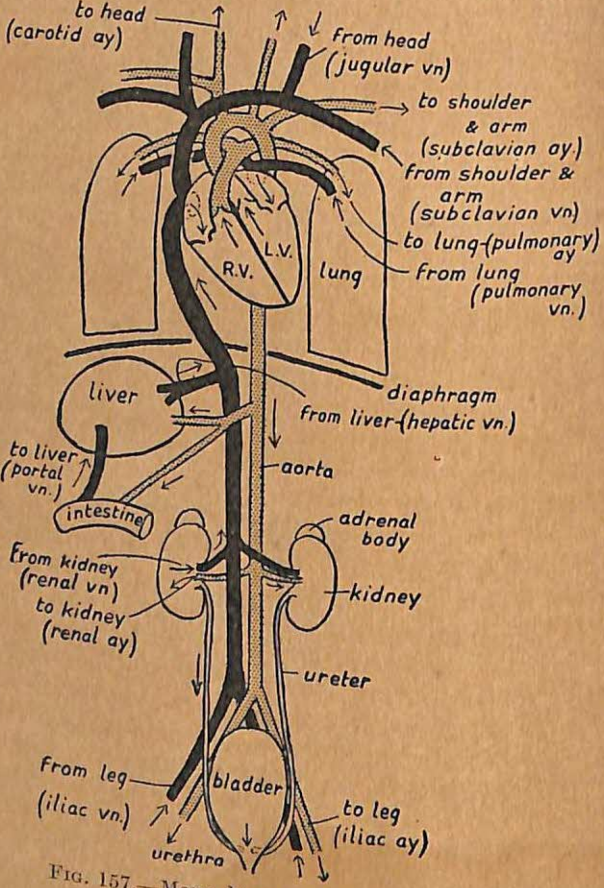

FIG. 157.—Man: heart and chief blood-vessels (ventral view—much simplified)

Deoxygenated blood from all parts of the body except the lungs flows into the *right auricle*. It is poured into the auricle through two large veins. The blood from the head and fore limbs is poured in through a vein called the *anterior vena cava.* The blood from the rest of the body (except the lungs) flows in through the *posterior vena cava.* At the same time oxygenated blood enters the left auricle through the *right* and *left pulmonary veins,* which bring blood from the lungs. These two veins unite just as they reach the auricle.

A large artery (*common pulmonary artery*) leaves the right ventricle, and divides into *right* and *left pulmonary arteries,* which carry deoxygenated blood to the lungs. (N.B.—*All other arteries contain oxygenated blood.*)

A large artery (the *aorta*) leaves the *left ventricle* and divides into branches, which go to all parts of the body except the lungs.

Valves at the base of the common pulmonary artery, and of the aorta, open to allow blood to pass from the ventricles into the arteries. The valves close to prevent backflow of blood.

How the Heart causes the Blood to Circulate

When the auricles are filled they contract. The valves between the auricles and ventricles open. Blood is forced from the right auricle into the right ventricle, and from the left auricle into the left ventricle. Thus deoxygenated blood fills the right ventricle, and oxygenated blood fills the left ventricle. The filled ventricles contract. The valves between the auricles and ventricles close. The valves at the base of the pulmonary artery and of the aorta open. Deoxygenated blood from the right ventricle enters the pulmonary artery, and is carried to the lungs to be oxygenated. Oxygenated blood from the left ventricle enters the aorta, and is carried all over the body.

The systemic or general circulation is the circulation of the blood through the aorta, its branches all over the body and capillaries in the tissues, and the veins which return it to the heart.

The hepatic portal circulation is the circulation of the blood from the portal vein through the capillaries in the liver to the hepatic veins which return it to the posterior vena cava.

The pulmonary circulation is the circulation of the blood through the pulmonary arteries, the lung capillaries, and the pulmonary veins.

QUESTIONS

1. Describe the blood of a Mammal.
2. What functions are performed by blood?
3. Explain the nature and function of lymph.
4. Describe the structure and work of the heart of a Mammal.
5. Describe the circulatory system of a Mammal, particularly noting the features and function of the pulmonary and hepatic portal systems.

CHAPTER XXI

EXCRETORY ORGANS, AND EXCRETION IN THE MAMMAL

Excretion

It has more than once been stated that cell activity results in the formation of certain waste products. These are useless, may be harmful, and must be expelled from the body. Such substances are *excretions*, and the process of their removal is termed excretion.

Animals, being very active, make much nitrogenous waste as a result of the breaking down of active protoplasm (p. 178). This is excreted together with water and dissolved salts by the kidneys, which are the chief excretory organs.

The Kidneys, and how Nitrogenous Waste is Excreted

The *kidneys* of Man (or Rabbit) are a pair of "kidney-shaped" dark red organs. They are attached to the dorsal wall of the head-end of the abdomen with their concave surfaces towards each other. From a notch in this surface of each kidney a stout tube (*ureter*) runs back and opens into the *bladder*. This is a large, thin-walled, pear-shaped sac lying in the hind end of the abdomen. It opens to the exterior by a soft-walled tube (*urethra*) between the thighs (figs. 148, 157).

At the notch on the surface of each kidney a large artery (*renal artery*) enters, and a large vein (*renal vein*) leaves the kidney. Inside the kidney the artery breaks up into a network of capillaries, which collect into the vein. The tissue of the kidney contains a multitude of very small, thin-walled *tubules* which open into the top of the ureter just before it leaves the kidney. The network of capillaries surrounds these tubules.

The blood entering the kidney contains a nitrogenous body called *urea*. It has already been stated (p. 178) that urea is *made by the liver*, and passed into the blood, which carries it to the kidneys. Water made as a result of tissue respiration has also passed into the blood. Some of this water is carried to the kidneys. The kidney tubules remove urea, waste water, and dissolved salts from the blood of the capillaries, which surround the tubules. The liquid is an excretion called *urine*. It flows down the tubules into the ureter, and collects in the bladder. From time to time it is expelled through the urethra.

The Skin, and How Sweat is Excreted

The *skin* is a thin layer of tissue covering the body of the animal. The skin of Man consists of an outer layer (*epidermis*) and an inner layer, or true skin (*dermis*). The outer part of the epidermis is made up of dead, dry, horny cells, which thus form a protective insensitive covering for the body. The inner part of the epidermis and the whole of the dermis is living tissue. The dermis contains many *nerve endings*, and is therefore sensitive. It also contains numerous *blood capillaries*. Many small coiled tubes lie in the dermis, run up through the epidermis, and open on the surface. These are the *sweat glands*. Each is surrounded by blood capillaries. The sweat glands make sweat from the blood in these capillaries. *Sweat* consists of water with dissolved carbon dioxide and traces of salts. It evaporates from the surface of the body, which thus gets rid of the waste water and carbon dioxide. Sweat is an excretion, and the skin is therefore an excretory organ.

The Skin, and How the Body Temperature is Regulated

The nerves in the skin control the changes of diameter o its blood-vessels, and thus control the amount of blood in the skin. The more blood there is in the skin the warmer the skin becomes, and the more heat it loses by radiation and conduction into the air. Increase or decrease of blood-flow through the capillaries also increases or decreases the production of sweat. Sweat evaporating into the air causes loss of heat (latent heat) from the surface of the body. Thus the rate of heat-loss of the body is controlled by the nerves, which act upon the blood-vessels of the skin. In warm-blooded animals[1] (Birds and Mammals) this control of heat-loss keeps the body temperature constant (Man 98·4° F.). Heat is also lost with the breath, the urine, and the fæces, all of which are at the same temperature as the body.

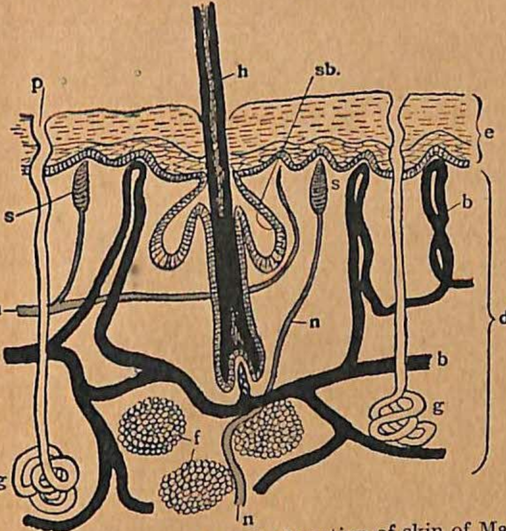

FIG. 158.—Diagram of vertical section of skin of Man
e = epidermis, *d* = dermis, *s* = sensory end organ, *n* = nerve, *h* = hair, *p* = opening of sweat duct, *sb* = sebaceous gland, *g* = sweat gland, *f* = fatty tissue, *b* = blood-vessel.

Hairs (found only in the skin of Mammals) are long cylinders of dead horny cells. Each hair is set in a pit in the epidermis. Little groups of grease-forming cells make an oily substance which keeps the hair soft. New cells are added to the base of the hair and thus the hair grows. The new cells are supplied by the dermis.

The Skin, and How the Sensation of Touch is Produced

Touch organs are little clumps of sensitive cells lying near the surface of the dermis. They are connected with the ends of the nerves in the dermis. The cells of the touch organs make the skin sensitive to touch stimuli (Part II, p. 133). The stimuli cause impulses to pass along the nerves to the brain, where the sensation of touch is " perceived."

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[1] All other animals are cold-blooded. They make little heat and do not regulate its loss. Their bodies are at the same temperature as the air or water in which they live, *i.e.* their body temperature varies.

QUESTIONS

1. Describe the excretory organs of a Mammal. What are the chief constituents of urine, and where and from what substances are they formed?
2. Describe and sketch the skin of a Mammal.
3. What are the chief functions of the skin of a Mammal?

CHAPTER XXII

THE FROG

Introduction

Now that the chief life processes of a Mammal have been studied we shall consider the *structure and mode of life of the Frog*. This animal is a smaller and simpler *Vertebrate*, but in general plan its structure is very like that of the Mammal. The Frog, however, is *cold-blooded* and lays *eggs*, from which *tadpoles* hatch out. After a time tadpoles change somewhat suddenly into small Frogs. This change is called *Metamorphosis*. The three stages, viz. egg, tadpole, and adult Frog, make up the *life-history* of the animal. The adult Frog is an *Amphibian, i.e.* it lives in damp places, and spends much of its time in water. Unlike fishes and tadpoles, the Frog breathes by means of lungs. *Its life processes are very like those of Mammal.* It crawls slowly, but leaps and swims strongly by means of its long and powerful hind limbs. It feeds on insects, snails, and slugs. It spends the winter hiding in holes or buried in the mud.

External Features

Examine living and dead Frogs. Note the movements of a living Frog. Sketch a dead Frog.

The *skin* is loose, moist, and makes a bitter slime. Unlike the skin of a Mammal it has no outer dead protective layer (p. 184). Hence in a dry atmosphere it rapidly loses water. For this reason the Frog can live only in moist surroundings. The skin is mottled yellowish green with black markings. It changes colour as the surrounding conditions change. *Hormones* (p. 178, and Part II, p. 136) act upon the *pigment cells* in the skin, which alter in size and shape, thus causing colour changes. Bright light, dry air, and warmth cause the skin to becomer lighter: the opposite conditions cause it to darken. The *body* is flattened from back to belly, and is somewhat pointed towards its hind end. The head has a pointed snout, and there is no well-marked neck.

The *head end* is termed *anterior*, the *hind end* is *posterior*. The *upper or back surface* is *dorsal*, the *belly or under surface* is *ventral*. In describing animals we shall frequently use these terms.

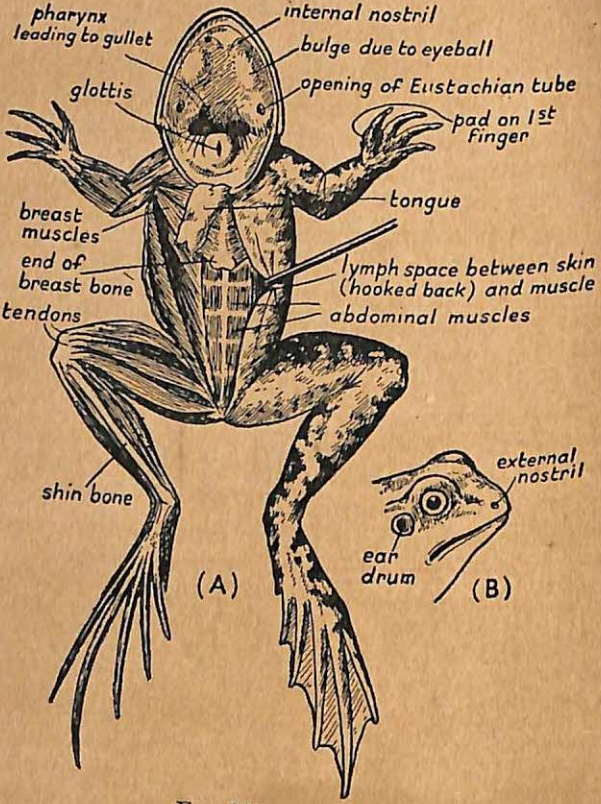


FIG. 159.—Frog (male)
(A) Partly skinned to show muscles (ventral view); (B) right side view of head

The "stream-lining" of the head and body aids the Frog to pass rapidly through the water. The *nostrils* and large *eyes* are on the dorsal surface of the head, so that the Frog can breathe and see when the rest of its body is submerged. There are no external ears, but there are a pair of circular *eardrums* on the surface of the head, just behind the eyes. The parts of the *limbs* are like our own (figs. 159, 160, 162), but the hand of the Frog has no thumb. The male Frog has a small swollen pad at the base of his first finger. The long toes are united by webs of skin, which aid in swimming.

How the Frog Feeds

Examine the mouth of a dead Frog. Note the very wide gape. The tongue is fixed to the floor of the mouth: the free end of the tongue points inwards.

The soft pink lining (*mucous membrane*) of the mouth contains a network of small blood-vessels. The *upper jaw* bears small pointed *teeth*; the *lower jaw* bears none. There are two patches of small teeth on the roof of the mouth. Insects and other small prey are caught by the sticky surface of the tongue, which is flicked over and out. The tongue then flicks back, carrying the prey into the mouth. Larger prey are seized by the jaws, and held by the pointed teeth. *With the mouth open, press the eyeballs.* They bulge down into the mouth cavity. The Frog makes its eyeballs bulge down in this way, and they assist in holding the prey, which is then bolted. Food is not chewed. The *glottis*, a small slit in the floor of the mouth, leads to the lungs. Two small openings in the roof of the mouth are the openings of the tubes (*Eustachian tubes*, figs. 159, 169) which lead to the *ear cavities*.

Skin the Frog—The skin contains a close network of blood-vessels. There are large *lymph spaces* between the skin and the muscles of the limbs and the body.

The Skeleton

As is usual among Vertebrates the skeleton is composed of *bone* and *gristle* (*cartilage*, Part II, fig. 79 (*a*)) and is *internal*. Muscles are attached to the outer surfaces of the bones.

The *chief parts of the skeleton* are: the *skull*, the *spine* (backbone, vertebral column), the *limb bones*, and the *bony girdles* to which the limb bones are attached.

The *skull* consists of a central bony brain-box (*cranium*) with a pair of *nasal capsules* fixed to its front end, and a pair of *auditory* capsules to its hind end. The *upper jaw* is fixed to the nasal and auditory capsules. The *lower jaw* is hinged to the lower hind corners of the skull. The eyes are lodged in large spaces (*orbits*) between the cranium and the upper jaw. A number of small holes on each side of the cranium are the exits of *cranial nerves* from the brain. The largest pair of holes are exits of the *optic nerves*, which are connected with the eyeballs. The *spine*, jointed to the hind end of the skull, is a dorsal bony axis which extends to the hind end of the body. *It consists of nine vertebræ* and a bony rod (*urostyle*).

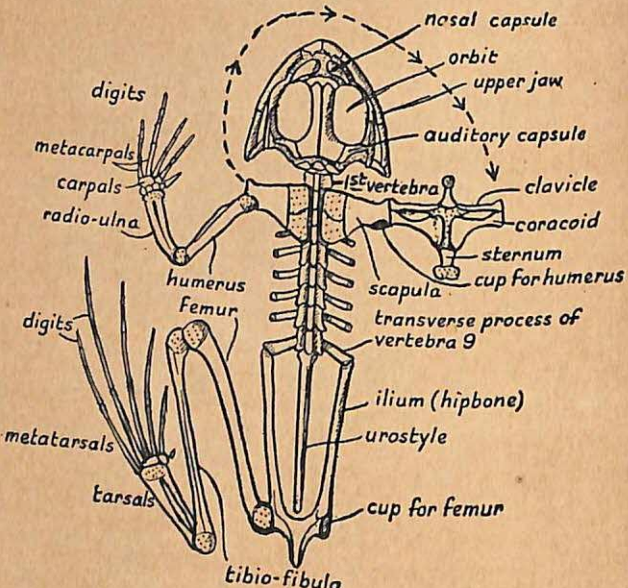


FIG. 160.—Skeleton of Frog (dorsal view)

A *typical vertebra* consists of a ventral bony cylinder (*centrum*) bearing a dorsal *neural arch*. A *neural spine* juts out from the crest of the arch. A pair of *transverse processes* come off from the sides of the arch. The space inside the arches of the successive vertebræ is the *vertebral canal*. It contains the *spinal cord.* The vertebræ are bound together by tough tissue (*ligament*). They also lock together. A pair of knobs on the posterior face of each vertebra fits into a pair of hollows in the anterior face of the next. Slight movement of each vertebra against its neighbours is possible. This makes the spine flexible. The vertebræ of the Mammal are similar (see figs. 161, 162).

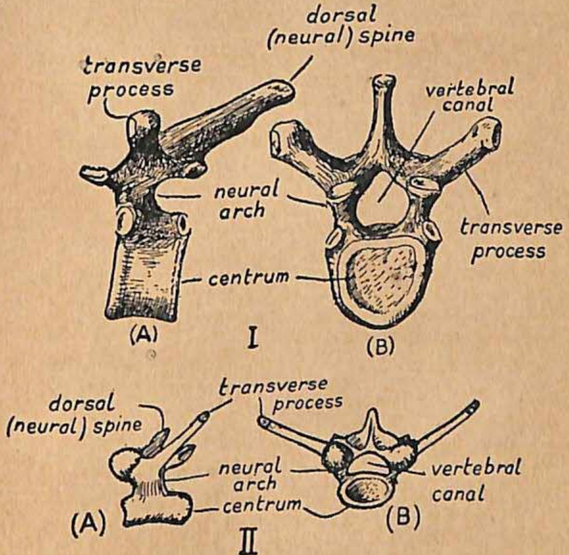


FIG. 161.

Vertebræ—I, of Man; II, of Frog
(A) View from left side
(B) View from in front (head end)

Small spaces between adjacent neural arches permit exit of paired *spinal nerves,* which come from the spinal cord.

The *first vertebra,* called the *atlas vertebra* because it supports the skull, has no transverse processes. The *ninth vertebra* of the Frog has very large transverse processes to which the *hip girdle* is attached. There are no ribs.

The *shoulder girdle* consists of a ventral breast-bone (*sternum*), a pair of dorsal triangular shoulder-blades (*scapulæ*), and two pairs of bony rods (*clavicles*, or collar-bones, and *coracoids*), which join the breast-bone to the shoulder-blades.

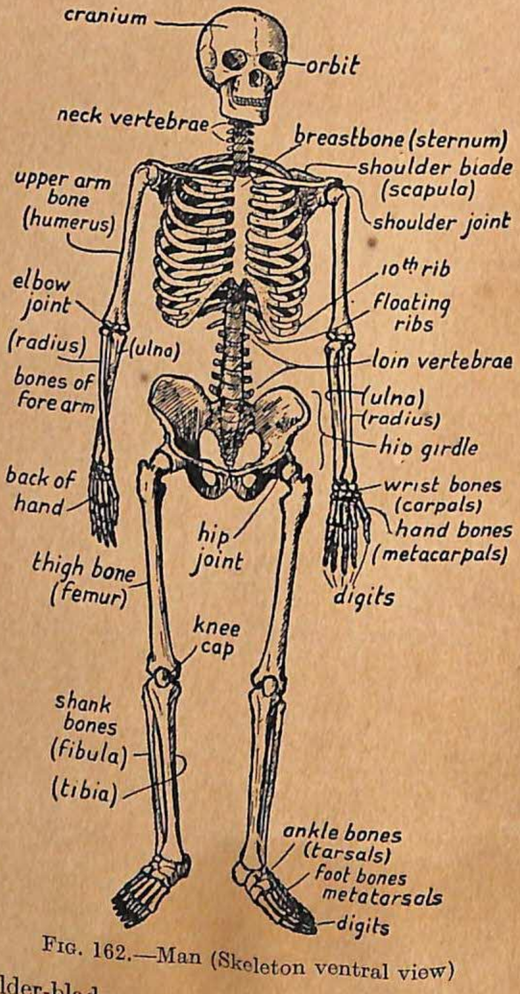


FIG. 162.—Man (Skeleton ventral view)

The shoulder-blades are movably united to the spine by muscles and sinews (*tendons*). Thus the girdle attaches the bones of the fore limbs to the spine. It also protects th heart and lungs.

The *hip girdle* is a long, narrow, bony U with its long side arms parallel to the spine. The top (anterior) ends of the long sidearms (hip-bones or *ilia*) are movably jointed to the transverse processes of the ninth vertebra. The girdle attaches the bones of the hind limbs to the spine.

The *bones of the fore limb*. There is a single upper-arm bone (*humerus*). Its rounded upper end fits into a cup-like hollow in the shoulder-blade. This junction is a *ball-and-socket joint*, and permits free movement of the upper arm. The forearm bone (*radio-ulna*) is really two fused bones. There are a number of small wrist bones (*carpals*), and four rod-like hand bones (*metacarpals*) which bear jointed *digits*.

The *bones of the hind limb* are a thigh-bone (*femur*), a shank-bone (*tibio-fibula*), which is really two fused bones, a number of small ankle-bones (*tarsals*), and five long foot-bones (*metatarsals*) which bear jointed *digits*. The upper end of the *femur* forms a ball-and-socket joint with a cup in the lower end of the *hip-bone*. In all such *movable joints* the bones are tipped with gristle, which aids smooth movement. The joint is enclosed in a bag of tough tissue (*joint capsule*), so that the bones shall not be torn apart. The joint is also lubricated by a fluid which bathes the ends of the bones.

In **Man**: (i) The large *cranium* forms a much greater part of the skull. (ii) *Ribs* attach the breast-bone to the spine. (iii) The coracoid bone is merely a coracoid process on the scapula. (iv) There is no urostyle, but some of the vertebræ in this region are fused. (v) The *radius* and *ulna* of the forearm are separate. (vi) The *tibia* and *fibula* are separate. (vii) Each limb has five digits.

The Functions of the Skeleton—It is an internal framework supporting the body and limbs. It protects the internal organs, and it provides a number of levers which are moved by muscles.

How the Frog Moves

When the skinned Frog was examined, the muscles of the body-wall and the limbs were seen (fig. 159). They are called *skeletal muscles*, because most of them are attached to bones. Their function is to move the body and limbs. *Nerves* ending in the muscles carry messages (*impulses*) to them from the brain and the spinal cord. The muscles respond by shortening and thickening (*contracting*). They pull upon the bones to which they are attached. The bones act as levers, and the joints as pivots (*fulcra*). The structure and mode of action of skeletal (voluntary) muscle has been described (Part II, p. 170). Some muscles (*e.g.* of the abdominal wall) are attached to other muscles.

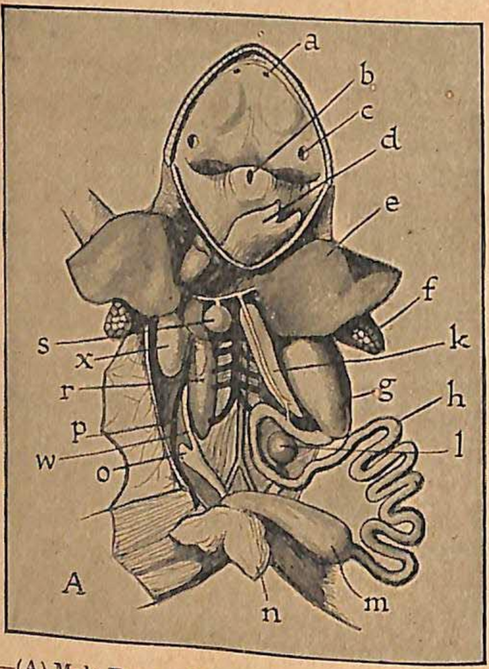


FIG. 163.—(A) Male Frog. Diagram of ventral dissection to show general arrangement of internal organs

a =internal nares, *b* =glottis, *c* =opening of left Eustachian tube, *d* =tongue, *e* =liver, *f* =lung, *g* =stomach, *h* =small intestine, *k* = pancreas, *l* =spleen, *m* =large intestine, *n* =bladder, *o* =seminal vesicle, *p* =renal-portal vein, *r* =kidney, *w* =kidney duct (conveys urine and sperm fluid), *s* =gall-bladder, *x* =testis (small ducts convey sperm from *x* to *w*).

The walls of internal organs contain a different kind of muscle (*plain involuntary muscle* of the stomach and intestines, see

Part II, p. 169). The wall of the heart contains a special kind of involuntary muscle (*cardiac muscle*, see Heart-beat, Part II, p. 168).

Open the belly of the Frog along the middle line, cut through the breast-bone, turn aside the muscular flaps of the body-wall. The body-cavity and the internal organs (*viscera*) are now exposed.

There is *no diaphragm* dividing the body-cavity into thorax and abdomen. The heart, with the great blood-vessels entering and leaving it, lies in the anterior part of the body-cavity. The *lungs* lie right and left of the heart. *Turn all of them forward* and expose the gullet (*œsophagus*).

The Alimentary Canal and the Digestive Glands

The *œsophagus* is a short, rather wide muscular tube. It leads into the J-shaped and rather wider *stomach*. The large, three-lobed, dark red *liver* lies to the right of, and partly covers, the stomach. The lower end of the stomach opens into the first loop (*duodenum*) of the *small intestine*. The *pancreas* is a long, narrow, pale yellow gland lying in the space between the duodenum and the stomach. The dark green spherical *gall-bladder* is attached to the lower surface of the liver, from which it receives bile. The *bile-duct* from the gall-bladder traverses the pancreas. Small *pancreatic ducts* open into it. The duct carries both bile and the pancreatic juice. It opens into the duodenum. (In **Man** and **Rabbit** the bile and pancreatic ducts are separate.) The coiled small intestine is about 4 in. long. Its lower end opens into a wide, large intestine (*rectum*) about 1 in. long. The hind end (*cloaca*) of the rectum opens to the exterior. The thin-walled *bladder*, in which the *urine* is stored, opens on the ventral wall of the cloaca. The intestines are attached to the dorsal body-wall by a fold of tough tissue (*mesentery*). The *spleen* is a dark red spherical gland attached to the mesentery near the lower end of the small intestine. Red blood corpuscles are produced and the old ones are destroyed in this gland.

How the Frog is Nourished

Food is digested in the *alimentary canal* and absorbed by its walls. The structure and general arrangement of the parts of the alimentary canal, the *digestive glands* and *juices, and their mode of action* are similar to those of Mammals (see pp. 165–167).

In the Frog, however, (*a*) there are *no salivary glands*, (*b*) the *gastric juice contains no rennin*, and (*c*) the *vermiform appendix* and *cæcum* are absent. Absorbed food is used as in Mammals (pp. 167–8).

How the Frog "Breathes"

The *respiratory organs* of the Frog are the *lungs*, the *mucous membrane of the mouth*, and the *skin*.

Carefully note the breathing movements of a living Frog. Examine the lungs of a dead Frog. Open one of them, and note the appearance of its internal surface.

The *lungs*, which hang in an anterior part of the body-cavity, are a pair of oval, greyish sacs. Each opens by a short *bronchus* into the voice-box (*larynx*). *There is no trachea.* The *larynx* is a cartilaginous box which opens into the floor of the *pharynx* by means of the *glottis*. The inner surface of the lung is thrown into many folds. The *pulmonary artery* enters the top of the lung. Its branches form a capillary network in the walls of the lung. The capillaries unite into veins, which collect into the *pulmonary vein*. This leaves the top of the lung.

Lung "Breathing" (*Pulmonary Respiration*).—With the mouth and the glottis closed the Frog lowers the floor of the mouth. Air flows in through the open nostrils. The nostrils close, the glottis opens, and the floor of the mouth is raised. Air is forced into the lungs, which expand slightly. Respiratory exchange of gases takes place between the air in the lungs and the blood in the lung capillaries (pp. 172, 174). After a short interval the abdominal muscles contract and force the viscera against the lungs. This pressure, and the recoil of the lung-walls, expels air from the lungs into the mouth. With the glottis and the mouth closed, the floor of the mouth rises, and the air is expired through the open nostrils. The lungs of the Frog are simple in structure, cannot deal with large volumes of air, and are not very efficient. The Frog uses them only at intervals, and respires mainly by means of the mucous membrane of the mouth, and the skin.

Mouth "Breathing" (*Buccal Respiration*).—Air is drawn into the mouth as already described. Instead of being forced into the lungs it is held in the mouth for a short time, and then expired. While in the mouth the air gives up oxygen to, and receives carbon dioxide and water vapour from, the blood of the capillaries in the mucous membrane.

Skin "Breathing" (Cutaneous Respiration).—The skin is richly supplied with blood capillaries. Respiratory exchange takes place between the blood in these capillaries and the air outside. This process is not accompanied by any breathing movements.

The Circulatory System—The *heart* consists of *two auricles* above and *one ventricle* below. A triangular thin-walled sac (*sinus venosus*) is attached to the back of the right auricle and opens into it. A bag of membrane (*pericardium*) encloses the heart.

Two large veins (right and left *anterior venæ cavæ*) open into the top corners of the sinus venosus. They bring blood from the veins of the head, fore part of the body, arms, and skin. One large vein (*posterior vena cava*) opens into the bottom corner of the sinus. It brings blood from the veins of the viscera, hind parts of the body, and the legs. A large artery (*truncus arteriosus*) leaves the ventricle, and divides into right and left branches. Each branch then divides into (*a*) a *pulmonary artery*, passing to the lungs and giving off an artery (*cutaneous artery*) to the skin, (*b*) an *aorta*, (*c*) an artery (*carotid artery*) to the head.

The Veins—Each *anterior vena cava* receives a *jugular vein* from the head and a *subclavian vein* from the arm. A *cutaneous vein* brings blood from the skin to the subclavian vein.

The *femoral veins* bring blood from the hind limbs. Some of this blood passes by the *renal portal veins* to the kidneys. Capillaries in the kidneys carry the blood to the *renal veins*, which unite with the *posterior vena cava*. The remainder of the blood from the hind limbs is carried by the *anterior abdominal vein* to the liver. Blood from the intestines is carried by the *hepatic portal vein* to the liver. Capillaries in the liver unite the *anterior abdominal vein* and the *hepatic portal vein* to the *hepatic veins*, which open into the *posterior vena cava*.

Thus all blood from the viscera, hind part of the body, and legs enters the *posterior vena cava*, and so reaches the *right auricle*. *Pulmonary veins* bring blood from the lungs, unite, and open into the *left auricle*.

The Arteries—The *right and left aortæ* curve outwards. They then run back and unite posterior to the heart. The united aortæ form the *dorsal aorta*. Branches of the dorsal aorta carry blood to the viscera and limbs.

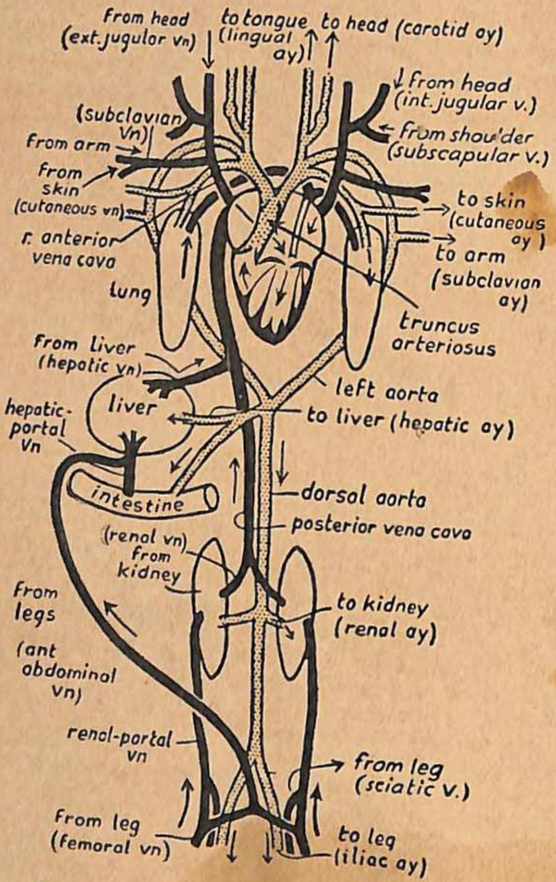
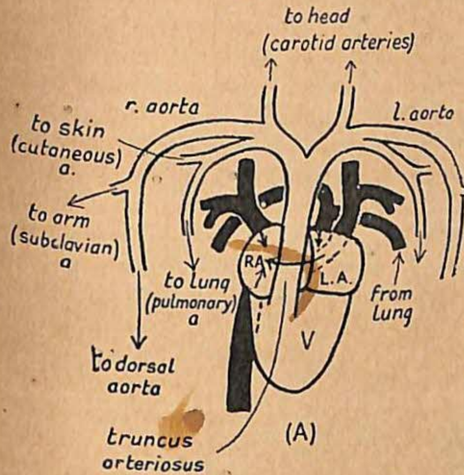


FIG. 164.—Frog: heart and chief blood-vessels (much simplified—ventral view)

Renal arteries carry blood to the kidneys, *subclavian arteries* go to arms, and *iliac arteries* go to the hind limbs. The *hepatic artery* goes to the liver.

In all cases the arteries *break up into capillaries*, which connect with the veins in all parts of the body.



The renal portal circulation is the circulation of blood from the renal portal veins through the capillaries in the kidneys to the renal veins. (The **Mammal** has no renal portal circulation.)

Pulmonary circulation is like that of the Mammal (p. 181).

The hepatic portal circulation is the circulation of blood from the hepatic portal vein and anterior abdominal vein through the liver capillaries to the hepatic veins.

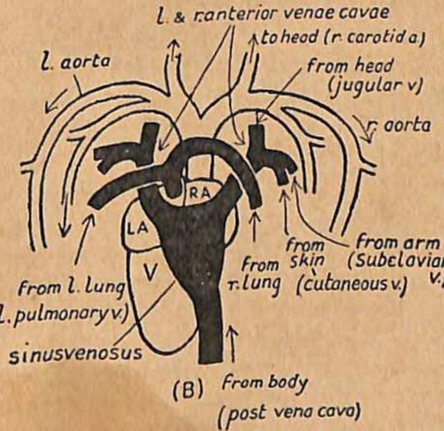


Fig. 165.—Frog: heart and roots of chief blood-vessels
(A) ventral; (B) dorsal view

How the Heart causes Blood to Circulate

The filled auricles contract. Deoxygenated blood is forced through the opening in the floor of the right auricle into the ventricle. Oxygenated blood is forced through the opening in the floor of the left auricle into the ventricle. The filled ventricle contracts. The valves guarding the openings from the auricles close. Blood is pumped into the truncus arteriosus. The first blood to leave the ventricle is mainly deoxygenated blood. This passes in the pulmonary artery to the lungs, and in the cutaneous artery to the skin, to be oxygenated. Mixed blood comes next, and passes through the aortæ to all parts of the body except the lungs, skin, and head. Last comes oxygenated blood, and this passes by the carotid arteries to the head. It is most important that the brain should be well supplied with oxygenated blood. Semi-lunar valves at the base of the truncus prevent backflow of the blood into the ventricle.

It will be noted that *the Frog's heart is less efficient than that of the Mammal.* The latter is so constructed that at each beat *all* deoxygenated blood leaving the heart goes to the lungs to be oxygenated, and that *all* parts of the body receive only oxygenated blood.

The Blood of the Frog

The *red blood corpuscles* of the Frog are oval plates each with a central oval nucleus (fig. 156). Otherwise the blood of the Frog resembles that of the Mammal both in structure and functions (pp. 176–179). The *lymph* of the Frog is like that of the Mammal (p. 176).

The *functions of the blood* are as already described under functions of the blood in the Mammal (pp. 178, 179).

The Nervous System

The *central nervous system* consists of the *brain* and the *spinal cord*, and of the *paired nerves* which connect them to different parts of the body. The *cranial nerves* connect the brain with different parts of the head. The last (10th) pair of cranial nerves go to the heart, lungs, and stomach.

The *spinal nerves* are connected with the muscles of the body and limbs. Each spinal nerve has two roots (dorsal and ventral) uniting it to the spinal cord.

A collection of special nerves (*sympathetic nervous system*) connect the spinal cord with the viscera.

The parts of the brain and the spinal cord and their work will be more fully described in a later chapter.

The *work of the brain* is to receive information concerning what is happening to the body, and to control the working of the different organs so as to promote the welfare of the animal

The *work of the nerves* is to carry messages (impulses) between the brain, the spinal cord, and the different parts of the body. *Impulses* reaching the brain and cord from the different organs inform the Frog concerning what is happening within and around it. Some of these impulses may result in the production of *sensations, e.g.* those of sight and smell. Impulses passing from the brain and cord to the different organs enable the Frog to work its muscles (see Part II, fig. 85, p. 133) and to make secretions, *e.g.* the digestive juices.

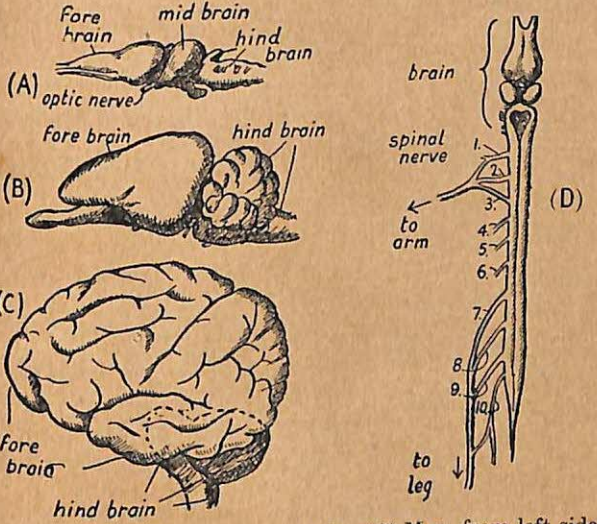


FIG. 166.—Brain: (A) Frog; (B) Rabbit; (C) Man, from left side; (D) brain and spinal cord of Frog (dorsal view)

The Sense Organs and the Senses

We usually speak of the "*five senses*," viz. *smell, touch, taste, sight*, and *hearing*. There are several others, *e.g.* the *sense of balance*, and the *muscular sense*, which tells us about the working of our muscles. *Sensations* are the result of *stimuli* acting upon *sensitive cells* in the various *sense organs*.

The *sense organs of smell* are situated in the nasal capsules (Part II, p. 132). The *sense organs of touch* are situated in the skin (p. 185, and Part II, p. 133). The *sense organs of taste* are situated in the tongue (Part II, p. 134). All these sense organs are simple arrangements of sensitive cells. The *sense organs of sight and hearing* are more complicated. Each kind of sense organ can be stimulated by *only one* kind of *stimulus*, and in each case *only one* kind of *sensation* is produced. From each sense organ a special nerve carries impulses to the brain.

How the Frog Sees

In structure and mode of action the eye of the Frog resembles a box camera. The front of the eyeball is a transparent window (the *cornea*), through which light enters the eye. Focussing is done, as in the camera, by a biconvex *lens*. This can be moved backwards and forwards within the eyeball. Between the cornea and the lens hangs a circular coloured curtain (the *iris*) with a central aperture (the *pupil*). The size of the pupil can be altered by the action of muscle fibres in the iris. This determines the amount of light reaching the back of the eyeball. Thus the iris corresponds to the diaphragm of the camera. The inside of the back of the eyeball has a lining of black pigment cells with a surface layer of sensitive cells and nerve tissue. This surface layer is the *retina*. It corresponds to the sensitive plate of the camera. Real, inverted, and diminished images are formed on it. The

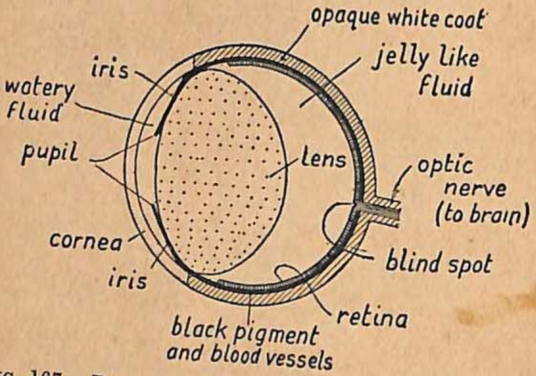


Fig. 167.—Diagram of eye of Frog (horizontal section)

stimuli so produced cause impulses to travel to the brain along the *optic nerve*, which connects the back of the eyeball with the brain. The spot at which the optic nerve connects with the retina is called the *blind spot*. It is not stimulated by light. Hence images formed on this spot are not seen.

Except in a few small details (compare figs. 167 and 168), the eye of Man is similar to that of the Frog, but focussing is effected by muscles (*ciliary muscles*), which alter the convexity of the lens. The action of the iris and the alterations of positions (convexity) of the lens are reflex actions, and the animal is not aware of them (Part II, pp. 141, 142).

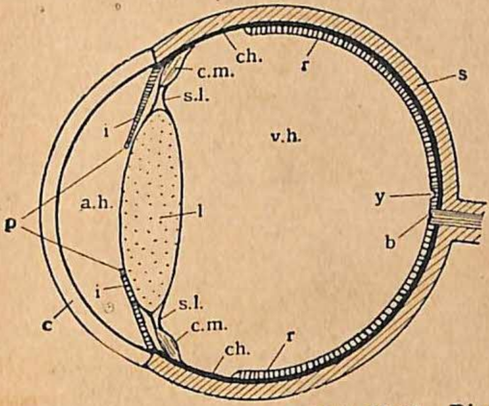


FIG. 168.—Right eye of Mammal (Rabbit, Man). Diagram of horizontal section (conjunctiva and eyelids omitted)

ah = aqueous humour, *vh* = vitreous humour, *b* = blind spot (no vision), *y* = yellow spot (most distinct vision), *c* = cornea, *ch* = choroid coat, *cm* = ciliary muscle, *i* = iris, *l* = lens, *p* = pupil, *r* = retina, *s* = sclerotic coat, *sl* = suspensory ligament. (*y* is not present in the Rabbit.)

How the Frog Hears

The chief part of the organ of hearing is the *inner ear*. It is a collection of *canals* and *sacs* lodged in the cavity of the *auditory capsule* (p. 190). It is filled with fluid, and its walls contain sensitive cells. The nerve of hearing (*auditory nerve*) connects these cells with the brain.

A passage, the *middle-ear cavity*, stretches from the inner ear to the side of the head. The *eardrum* (p. 189) closes the outer end of this passage. A bony rod (*columella*) extends from the drum to the inner ear. Sound waves strike the drum. It vibrates, and its vibrations are carried by the columella to the inner ear. They cause the fluid in the inner ear to vibrate.

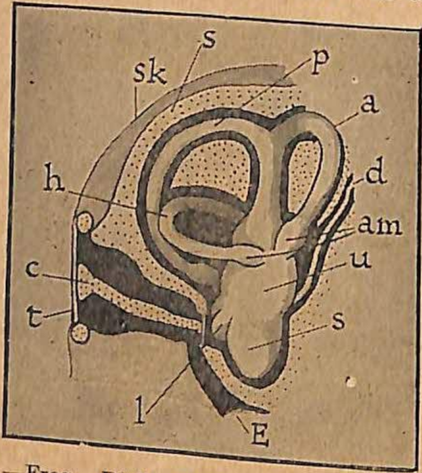


FIG. 169.—Frog. Right middle and inner ear seen from in front and slightly exterior (diagrammatic)

t=tympanic membrane (eardrum), *c*=columella crossing middle-ear cavity, *l*=lagena (=cochlea of Mammal), E=Eustachian tube, *sk*=skin of head, *s* (upper)=skull, *h*=horizontal (exterior) canal, *a*=anterior vertical canal, *p*=posterior vertical canal, *am*=ampulla of canal, *d*=part of endolymphatic duct, *u*=utricle, *s* (lower)=saccule.

The vibrations stimulate the sensitive cells. Impulses pass along the auditory nerve, and a sensation of hearing is produced in the brain. Vibrations of the fluid in the canals of the inner ear (see fig. 169) result in sensations of balance.

The ear of Man (Part II, fig. 98, p. 155) is similar to that of the Frog, but it is rather more complicated. Man has also an outer ear, which is a kind of flap by which sound waves are collected and reflected to the eardrum.

How the Frog gets rid of (Excretes) Waste Matter

We have said that the chief waste products formed in the animal body are carbon dioxide, water, and urea. Most of the carbon dioxide and some water vapour are got rid of by the respiratory organs. Nitrogenous waste in the form of urea dissolved in water is got rid of as urine by means of the kidneys, which are the chief excretory organs.

Turn the liver forward. This exposes the kidneys and the reproductive organs. Identify and sketch.

The *kidneys* are a pair of oblong, dark red glands lying in the middle of the body-cavity and just ventral to the spine. A *urinary duct* from each kidney opens on the dorsal wall of the cloaca. Urine passes down the ducts and into the *bladder*, which periodically discharges it into the *cloaca* and it is expelled from the body.

Note a pale yellow patch on the surface of each kidney. This is the *adrenal body*. Note also that the renal artery enters, and the renal veins and urine duct leave the inner border of the kidney. The renal portal vein enters its outer border.

How the Frog Reproduces

The **male Frog** has a pair of oval white *testes* attached to the kidneys by folds of tissue. *Sperm fluid* containing *spermatozoa* (male gametes—see Part II, fig. 73 and p. 114) is made in the testes, and passes through *sperm ducts* to the kidneys and then with the urine down the urinary ducts. It collects in a sperm sac on the course of each duct and is discharged to the exterior during the breeding season.

The **female** has a pair of sac-like *ovaries* similarly placed to the testes. Eggs (*ova*) are shed into the body-cavity. By unknown means they enter the upper open ends of a pair of *oviducts*. These are coiled white tubes which open below on the dorsal wall of the cloaca. Ova passing down the oviducts become coated with slime and are discharged to the exterior during the breeding season.

In the breeding season the male clings to the back of the female and both enter the water. The female sheds her eggs, and the male pours sperm over them. The slime coating the eggs swells, forming a floating mass of jelly (*spawn*) with eggs and spermatozoa embedded in it. The spermatozoa wriggle through the jelly, enter the eggs, and fertilise them. The eggs are black above, white and filled with *yolk* below. The yolk is the food of the young embryo.

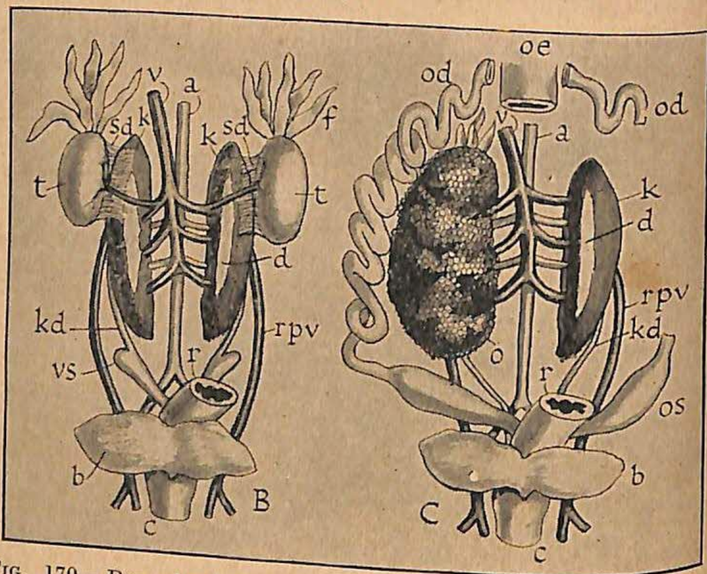


FIG. 170.—Reproductive and excretory organs of Frog (diagrammatic). B = male, C = female (left ovary, oviduct, and fat body omitted)

a = abdominal aorta giving renal arteries to kidneys, *b* = bladder, *c* = cloaca, *d* = adrenal body, *f* = fat body, *k* = kidney, *kd* = kidney duct (carries sperm as well as urine in male), *o* = ovary, *od* = oviduct, *os* = ovisac, *r* = rectum, *v* = inferior vena cava receiving renal veins, *rpv* = renal portal vein, *vs* = seminal vesicle (*od* (above) and *kd* (slightly below) open into back of *c*; *b* opens into front of *c* at slightly lower level).

How the Frog Develops from the Fertilised Egg

The tiny black *embryo* is seen coiled up within the egg. Moisture and warmth aid its development. The young *tadpole* with large oval head and long, laterally flattened tail hatches out at about two weeks. It has a sucker-like *cement gland* on the under-surface of its head, by which it remains attached to the remains of the yolk for some days. It feeds on the yolk, and respires dissolved oxygen through its skin. Next it swims away and attaches itself to a water plant or similar support. It develops a pair of *horny jaws*, a pair of *small eyes*, and a pair of *auditory organs*. The last named are at first simple pits on the side of the head. Three thread-like *external gills*, containing many blood capillaries, grow out from each side of the neck region. The tadpole respires by means of these as well as by its skin. It feeds on vegetable matter. During the fourth to sixth weeks the tadpole rapidly grows and develops. A long, coiled *gut* opening by an *anus* near the root of the tail can now be seen through the body-wall. The external gills wither, and four *gill slits* with *internal gills* partly covered by a *gill cover* appear on each side of the neck region. The gill slits connect the *pharynx* with the exterior. Water is drawn into the mouth and pharynx, passes over the gills, and out behind the gill covers. The tadpole now resembles a fish, respiring dissolved oxygen by means of its internal gills. At about eight weeks *metamorphosis* takes place, the tadpole changing rather suddenly into a small Frog. *Hind limbs* appear, the horny jaws are shed, and the mouth enlarges. A pair of *lungs* grow out from the pharynx, the *fore limbs* develop, the gills wither, and the gill slits close. The young Frog now rises to the surface of the water from time to time, and fills its mouth and lungs with air. It respires like the adult Frog, by means of its mouth, lungs, and skin. At about twelve weeks the tail disappears, being absorbed and used as food. The young Frog now eats animal food, leads an amphibious life, and grows into an adult Frog.

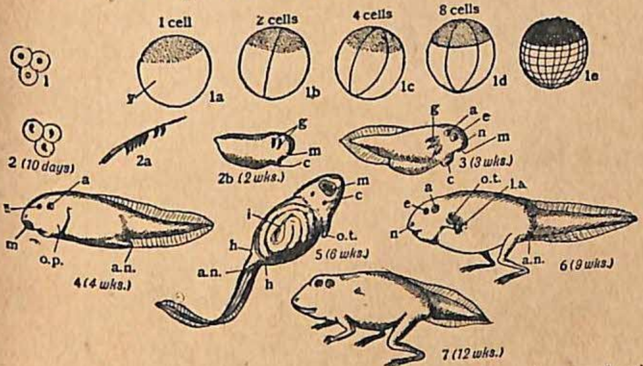


FIG. 171.—Diagrams of stages in development and metamorphosis of Frog. 1. Freshly laid eggs; 1*a* to 1*e*. Eggs undergoing segmentation; 2. Eggs containing young tadpoles; 2*a* and 2*b*. Freshly hatched tadpoles; 3 to 7. Later stages of development (not drawn to same scale; 7. Tadpole undergoing metamorphosis into young Frog)

g = external gills, *m* = mouth, *a* = auditory organ, *e* = eye, *n* = nostril, c = cement gland, *i* = intestine, *op* = operculum (gill cover) covering internal gills, *ot* = opercular tube, *h* = rudiment of hind limb, *an* = opening of cloaca.

QUESTIONS

1. Name some features of structure which are peculiar to the Frog. Of what value are they to the animal?
2. Sketch the skeleton of the Frog. In what respects are the pectoral girdle (shoulder girdle) and pelvic girdle (hip girdle) peculiar?
3. Describe and sketch the digestive system of the Frog.
4. Describe the structure and work of the heart of the Frog.
5. Sketch and describe the circulatory system of the Frog. Note how it differs from that of a Mammal.
6. Describe the development of the Frog from the egg to the adult state.

CHAPTER XXIII

NUTRITION IN THE GREEN PLANT

How the Green Plant Feeds

You have already been told that an animal takes in complex food materials, often in solid form. These foods are digested or made soluble before they can be used within the animal body. They are either built up into protoplasm, or are oxidised with the liberation of energy. In an earlier chapter (Part II, pp. 124–126) it was briefly stated that the green plant does not take in ready-made foods, but takes in simple substances which it builds up into foods. Carbon dioxide is taken in by the leaves. Water and dissolved mineral salts are taken in by the root-hairs. From these simple substances the plant makes complex food-stuffs, which are used either in building up protoplasm or in liberating energy. That is, they are used just as similar foods are used in the animal body. We have now to consider how the plant takes in these simple substances, how it builds them up into foods, and how the foods are used.

To show that the green plant can obtain all the food materials it needs from the air and from a solution of mineral salts in water.

Make a solution containing 1000 c.c. of distilled water, 1 grm. of calcium nitrate, ·25 grm. each of potassium nitrate, potassium acid-phosphate, and magnesium sulphate, and 2 drops of ferric chloride solution. Take several wide-mouthed bottles, each of about one quart capacity. Cover with black paper, and sterilise. Fit each with a cork bored with three holes. Through one hole pass a glass delivery tube reaching to the bottom of the bottle. Through the second hole pass a glass tube reaching just below the cork. Take a Bean seedling with roots about 3 in. long, and plug it into the third and widest hole by means of cotton-wool. Having fixed a seedling into each cork, about one quarter fill each bottle with the solution, and arrange its cork so that the roots of the seedling are completely immersed. Leave in a warm, light place. From time to time aerate the solution by blowing air in through the long delivery tube. Renew the solution as required. Note that the seedlings show continuous healthy growth. Compare the seedlings with others, some grown in soil, and some in distilled water.

The Structure of the Green Leaf

You have already been told (Part II, p. 125) that carbon dioxide enters the plant by way of small pores, called *stomata* (Gk. *stoma* = mouth). These are found mainly in the leaves, but they occur also in the other green parts of the plant. The leaf is covered with a skin, or *epidermis*, consisting of a single layer of flat cells of irregular outline. They fit together without intercellular spaces. Their walls are of cellulose, but the outer walls are rendered practically air- and water-proof by a coating of a substance called *cutin*. These cells contain no chloroplasts. The epidermal cells of the other green parts, *e.g.* the stem, are similar, but are usually narrower and of less irregular outline. Here and there among the epidermal cells—especially those of the leaf—are a number of small oval openings. These are the *stomata*. Each *stoma* is bounded by a pair of half-moon-shaped cells. These are the *guard cells*. They contain *chloroplasts*, which are small oval or disc-like green bodies. Their colour is due to a green pigment called *chlorophyll* (Gk. *chloros* = green, *phullon* = leaf). The walls of the guard cells are peculiarly thickened so that the cells change their shape as the amount of sap in them changes. When they are full of sap the inner walls of the guard cells curve apart, and the stoma opens widely. When the cells have little sap the inner walls come together, and the stoma is partly closed. We shall see the use of this later.

Place a leaf in boiling water for one minute. The epidermis can then be stripped off. Mount a piece of epidermis in distilled water on a glass slide. Examine under the microscope. Sketch.

Repeat, using a leaf which has been kept for twenty-four hours in darkness. Note the difference in shape of the stomata.

Between the epidermis of the upper and lower surfaces of the leaf is the ground tissue or *mesophyll* (Gk. *mesos* = middle, *phullon* = leaf). Immediately below the upper epidermis are two or three rows of cylindrical cells set closely side by side. These form the *palisade parenchyma.* The remaining mesophyll is *spongy parenchyma.* Its cells are rounded and irregular, with large intercellular spaces. The mesophyll cells contain many chloroplasts. Small *veins* (vascular bundles of the leaf—Part II, p. 126) end among the mesophyll cells.

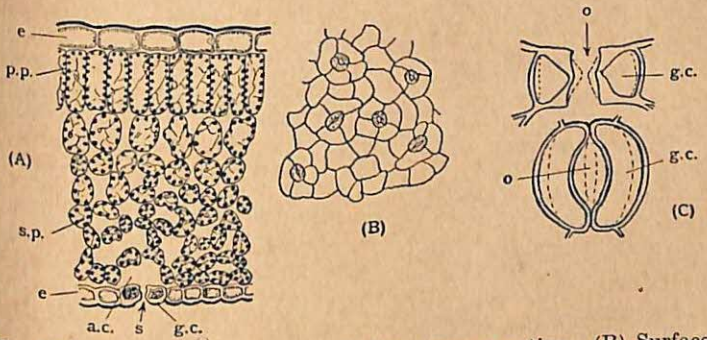


FIG. 172.—Leaf of Wallflower. (A) Transverse section; (B) Surface view of epidermis with stomata; (C) Stoma: *above*, vertical section; *below*, seen from exterior. Dotted lines show contours of guard cells when stoma closes

e = epidermis (external wall cutinised), *pp* = palisade parenchyma, *ac* = air chamber, *s* = stoma, *gc* = guard cell, *o* = aperture of stoma, *sp* = spongy parenchyma.

How the Green Plant obtains Carbon Dioxide

Air enters the leaf by way of the stomata, and passes into the intercellular spaces. The air contains about ·03 per cent. carbon dioxide. Some of this gas passes through the walls of the cells bounding the spaces, and dissolves in the cell-sap.

When the plant is exposed to fairly bright light it makes food more rapidly. A more rapid and plentiful supply of carbon dioxide is needed. The plant obtains its additional supply by using the carbon dioxide which is made in the cells as a result of the process of respiration. That is, the plant keeps and uses the carbon dioxide produced in respiration, instead of giving it out into the air as an animal does. In darkness food-making ceases, and the carbon dioxide produced in respiration is not needed. The plant then gives it out into the air.

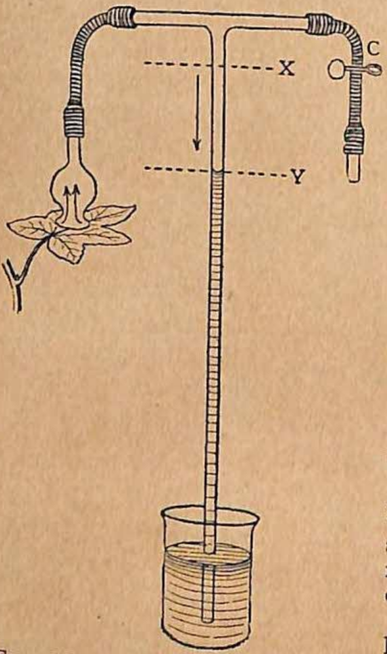


FIG. 173. — Porometer. To show presence of stomata (and intercellular spaces) in a green leaf
C = clip, X = original level of water, Y = new level of water.

To show the Presence of Stomata and Intercellular Spaces in a Green Leaf—Fit up the apparatus shown in fig. 173. Fix the funnel to the surface of the leaf with tallow or seccotine. Smear the rubber tubes and joints with vaseline. Open clip C. Suck water up to the tube X. Close clip. Allow apparatus to stand. In time the water-level falls to Y, showing that air has entered the apparatus. It must have done so through the area of leaf under the funnel. Stomata must be present in this surface of the leaf. Air spaces must be present in the leaf in order that air may reach these stomata. Repeat the experiment, using the other surface of the leaf.

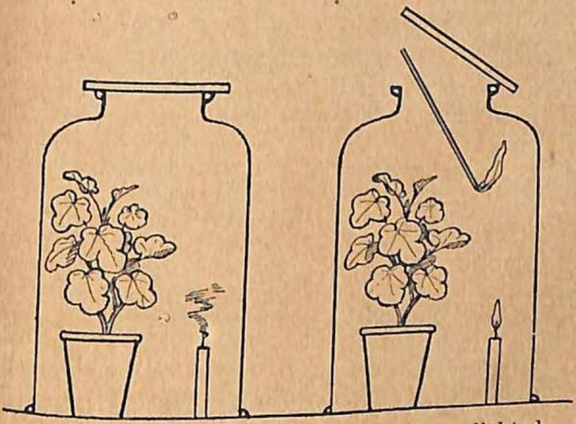
Some leaves (Iris, Rhubarb) have stomata on both surfaces; some floating leaves (Water Lily) in the upper surface only. Most leaves have them mainly in the lower surface. A few leaves (submerged leaves of water plants) have no stomata.

How the Green Plant uses Carbon Dioxide in making Carbohydrate Food-stuffs (Sugar and Starch)

The chlorophyll in the chloroplasts has the remarkable power of being able to absorb energy from sunlight. It gives up this energy to the protoplasm of the cells which contain the chloroplasts. The protoplasm uses this energy in building up sugar from carbon dioxide and water in the cell-sap. This is a chemical action which cannot take place unless energy is supplied, and can take place only when the plant is exposed to light. The process of sugar formation from carbon dioxide and water in the presence of light is termed *Photosynthesis.* The reaction may be shown as follows:—

$$6CO_2 + 6H_2O + \text{Energy} \rightarrow C_6H_{12}O_6 + 6O_2.$$

To show that in Light the Green Plant absorbs Carbon Dioxide from the Air and gives off Oxygen, but does not do so in Darkness—



(*a*) Candle extinguished owing to lack of oxygen.

(*b*) Candle relighted. Oxygen replaced (produced during photosynthesis).

FIG. 174.—Photosynthesis. During exposure to light a green plant absorbs carbon dioxide and liberates oxygen

Place a growing potted plant and a candle in a large wide-mouthed bell-jar as in fig. 174. Light the candle, and close the mouth of the jar with a greased cover-plate. After a time the candle uses up all the oxygen it can, and then goes out. It produces carbon dioxide and water vapour. Leave the jar for several hours in bright light. Insert a lighted taper, and try to relight the candle. It relights, and burns for some time. This shows that a fresh supply of oxygen has been produced in the jar, and carbon dioxide removed by the plant.

Repeat the experiment, keeping the plant and jar in darkness. The candle will not relight. This shows that the plant kept in darkness has not removed carbon dioxide, nor has it set free a fresh supply of oxygen in the jar.

To show the Presence of Sugar in a Green Leaf after exposure to Light—Take a fairly young leaf from a plant (*e.g.* Cabbage) which has been growing in light. Grind the leaf in a mortar with about 10 c.c. of water. Filter the extract into a test-tube. Add 5 c.c. Fehling's solution. Boil. A yellow-red precipitate of cuprous oxide shows the presence of sugar.

The sugar gradually changes into starch, which is insoluble. The removal of the sugar from the sap makes room for more sugar. Thus, so long as the leaf is exposed to light, and carbon dioxide and water are available, sugar is being formed in the mesophyll cells and is being changed into starch.

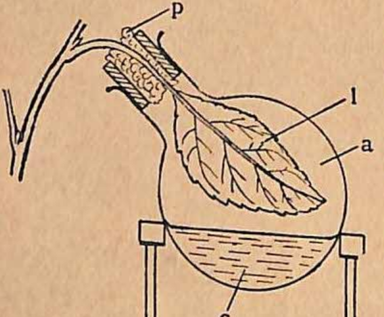


FIG. 175.—To show that a green leaf does not form starch in absence of carbon dioxide (*i.e.* no photosynthesis occurs)

p = cotton-wool plug soaked in lime-water, l = green leaf, c = caustic potash, a = air freed from carbon dioxide.

To show the Presence of Starch in a Green Leaf which has been exposed to Light—Take a green leaf which has been exposed to light for some hours. Boil in water for three minutes to kill the protoplasm. Immerse in a test-tube of alcohol standing in a beaker of hot water. The chlorophyll is extracted, and colours the alcohol. Wash the leaf, and place it in an evaporating dish containing iodine solution. The leaf turns blue-black, showing the presence of starch.

Repeat the experiment, using a variegated leaf. No starch is found in the non-green parts of the leaf. This shows that starch is not formed in the absence of chlorophyll.

To show that Starch disappears from a Leaf kept in the Darkness, and that no more is made unless the Leaf be exposed to Light—Use the same plant as in the last experiment. Place it in darkness for forty-eight hours. On each side of one of its leaves clip two small cardboard discs so as to cut off the light from the covered parts of both surfaces. Place the plant in light for twenty-four hours. Detach the leaf. Treat it as in the last experiment. No starch is found in the covered part of the leaf, but it is found in the exposed parts. This shows that in darkness starch disappeared from the leaf, and that on later exposure to light a fresh supply of starch appears in only the exposed parts of the leaf.

To show that Carbon Dioxide is needed for Starch Formation.—Keep a potted plant (Fuchsia, Primula) in darkness until its leaves are free from starch. Test a leaf to make sure. Into a large (1000 c.c.) flask containing 20 c.c. of strong caustic potash solution insert a leaf as shown in fig. 175. Plug the flask with a split rubber stopper and plug the leaf-stalk in position with cotton-wool soaked in lime-water. Plug another leaf into a similar flask containing 20 c.c. of water. Leave in bright light for six to eight hours. Test both leaves for starch. None is found in the leaf in the flask containing caustic potash. (The caustic potash has absorbed the carbon dioxide of the air in this flask.) Starch is found in the other leaf.

How Carbohydrates (Sugar, Starch) are used in the Green Plant

It has already been shown that starch stored in the leaves during periods of light disappears from them during periods of darkness. It is changed by enzymes (*diastase* and *maltase*) first into maltose, and then into glucose. This is just how starch is digested in the animal body. The sugar dissolves in the cell-sap, and gradually passes into the sieve-tubes (Part II, fig. 80, p. 121) of the phloem. These carry it to all parts of the plant. It passes from the tubes into the sap of the cells of the different plant organs. Oxygen taken in by the plant in the process of respiration (to be presently described) oxidises the sugar. Carbon dioxide and water are formed, and energy is set free. This reaction may be shown thus:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}.$$

Thus, in the green plant as in the animal, carbohydrates are changed into glucose, which is the source of energy within the organism.

Why the Plant needs Energy—Although the plant is much less active than the animal, plant organs often perform movements. Energy is needed for these. The plant also grows as long as it lives, *i.e.* it makes new protoplasm. Hence it continually needs energy for the chemical actions which take place when the new protoplasm is made.

How the Green Plant obtains Water and Dissolved Mineral Salts

It has already been explained that the root-hairs (Part II, p. 124), and these only, take in a dilute solution of salts from soil-water. In addition to the air which is found in the spaces between the soil particles there is soil-water, which saturates the particles and forms a film on their surface. The water dissolves salts from the soil. Among these salts are nitrates, sulphates, phosphates, and chlorides of potassium, sodium, calcium, magnesium, and iron. These are taken in as a dilute solution by the root-hairs. The saline solution travels to all parts of the plant. Much more water is taken in than is needed by the plant. The excess is got rid of by way of the stomata. This loss of water vapour from the plant into the air is termed *transpiration*. We have now to consider how the saline solution enters the plant, how it travels to all the tissues, and how the excess water is got rid of into the air.

Root-hairs

Examine under the hand-lens the ends of the rootlets of seedlings (e.g. *Mustard grown on damp flannel*).

About ½–1 cm. behind the tip of each rootlet is a short zone of glistening thread-like *root-hairs*, which form a white "felt" about ¼ cm. thick on all sides of the rootlet. The tip of the rootlet ends in a growing-point covered by a small thimble-shaped *root-cap*. The short length of rootlet between this and the root-hair zone is the region of most rapid growth (Part II, p. 158).

As the rootlet lengthens and pushes its tip forwards between the soil particles, new root-hairs are formed in front of the root-hair zone, and old root-hairs die off behind.

Examine under the microscope a mounted transverse section of the root-hair region of a young root. Sketch.

Each root-hair is a finger-like outgrowth of a brick-shaped cell of the surface layer of the root. It has a cellulose wall lined with a thin layer of protoplasm. A nucleus lies in the protoplasm near the tip of the root-hair. The central cavity of the cell and its root-hair is full of clear sap.

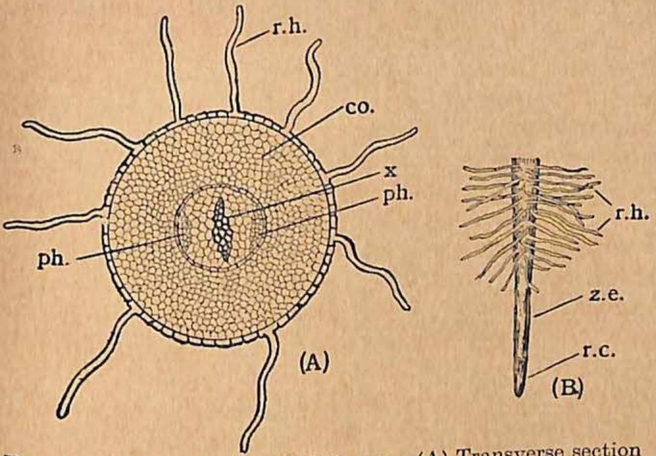


FIG. 176.—Young root of Wallflower. (A) Transverse section (magnified—low power); (B) Part of root (hand-lens)

rh = root-hairs, *ze* = zone of elongation ('growing zone'), *rc* = root-cap, *x* = xylem, *ph* = phloem, *co* = cortex. Cambium lies between xylem and phloem, but not yet clearly differentiated.

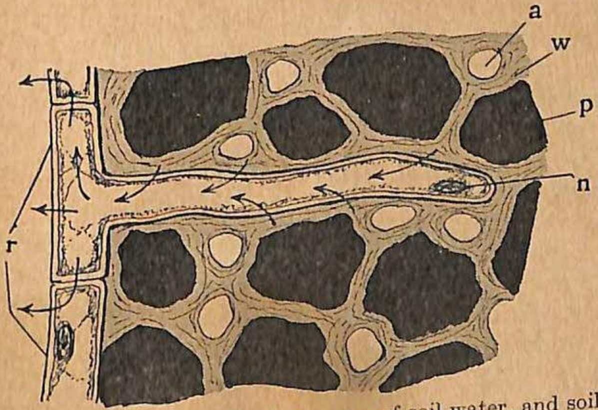


FIG. 177.—Root-hair, soil particles, film of soil-water, and soil-air

a = air, *w* = water, *p* = soil particle, *r* = root, *n* = nucleus of root-hair cell

How Water and Dissolved Salts enter the Root-hairs and Travel to the Leaves

The sap of the root-hairs contains sugar and other substances in solution. Their presence causes the sap to exert a force called *osmotic pressure* (Gk. *osmos* = push). This force causes a dilute solution of salts in water to pass from the film surrounding the soil particles through the cell-wall and layer of protoplasm into the sap of the root-hair. The saline solution taken into the cell-sap causes a great osmotic pressure to be set up between it and the sap of the neighbouring cells of the root. Salts and water therefore pass from the root-hairs into the neighbouring cells. The process is repeated from cell to cell, deeper and deeper into the root. The deep-seated cells which lie next to the xylem strands of the central core of the root give up water and salts into the xylem vessels (Part II, p. 126). The vessels carry water and salts from root to stem, and into the leaves. Here the xylem vessels of the veins end among the mesophyll cells.

How the Transpiration Current of Water and Dissolved Salts from Root to Leaves is Produced

The mesophyll cells are full of watery sap. The sap continually loses water, which passes through the protoplasm layer and cell-walls and evaporates into the air in the intercellular spaces. From these spaces it diffuses by way of the stomata into the air outside. This loss of water is *transpiration*, and it is "made good" from the *transpiration current*. As the mesophyll cells lose water they draw fresh supplies from their deeper-seated neighbours, osmotic pressure being set up between cell and cell. The cells next to the xylem vessels draw water and salts from the cavities of the vessels. There are continuous columns of water within the xylem vessels, from the ends of the vessels in the leaves down to their beginnings in the roots. The loss of water from the tops of these columns into the mesophyll cells sets up a tension, or "pull," in the columns. This causes water and salts to travel up the columns from the roots, by way of the stem, into the leaves. The xylem vessels of the root are continually supplied with water and salts from the sap of the cells around them. These cells, we have seen, draw supplies from the root-hairs. To make up this loss, the root-hairs absorb water and salts from the film surrounding the soil particles. The absorption of water and salts by the root-hairs and the upward flow of the transpiration current are therefore due to the tension in the water columns, and this is due to the loss of water transpired by the leaves. The tension produced is very great, and is able to raise water to the tops of the highest trees, some of which are more than 200 ft. in height.

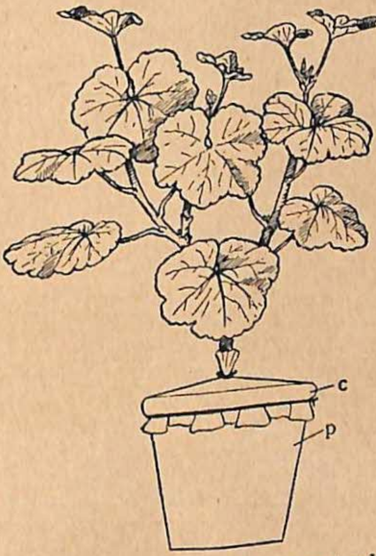


Fig. 178.—To show that a green plant loses water by transpiration
c =cover, *p* =pot. Both waterproofed.

To show the Loss of Water from a Green Plant by Transpiration—Take a well-watered young potted plant. Plug the hole in the bottom of the pot. Stop the pores in the pot by smearing it with vaseline. Tie a piece of rubber sheeting over the top of the pot (see fig. 178), vaselining between the sheet and the stem. Weigh the pot and contents. Leave in moderate light and warmth. Re-weigh after twenty-four hours. A considerable loss of weight is noted, showing that the plant has lost water by transpiration. Repeat the experiment, using a cut leafy shoot standing in a similarly air-tight vessel of water.

To show the Intake of Water by a Green Plant or Leafy Shoot—Fit up the apparatus shown in fig. 179 (a potometer). By opening the cock C for a short time, ensure that the vessel and the narrow-bore tube are filled with water. Note the exact position of the end of the water column in B. Stand the apparatus in moderate light and temperature. Note and measure at intervals the distance the water has receded along the tube. The rate of movement of the end of the water column shows the rate at which the plant is taking in water. The apparatus should be set up twenty-four hours before use. If a cut shoot be used, it must be cut under water, and its cut end kept continuously under water. Test the effect produced upon the rate of intake of water by placing the plant in sunlight, darkness, damp atmosphere, and dry atmosphere.

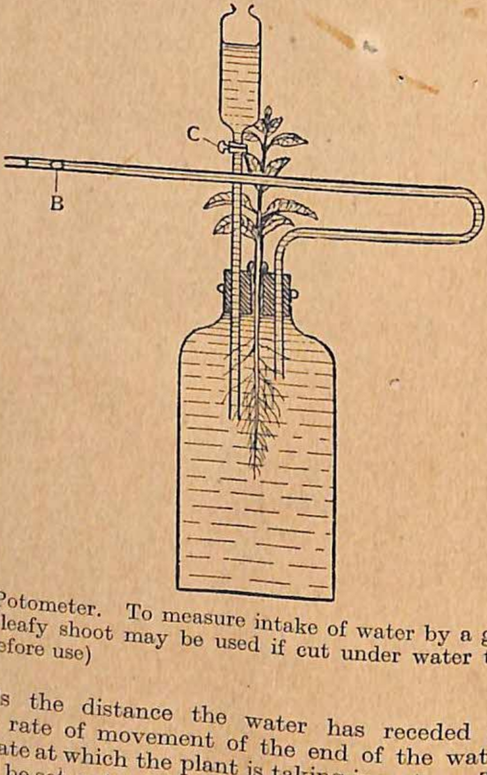


FIG. 179.—Potometer. To measure intake of water by a green plant. (A cut leafy shoot may be used if cut under water twenty-four hours before use)

Root Pressure

For a short time during spring there is another force which aids the upward flow of water in the green plant. Plants which live through the winter store much starch for use when growth becomes active in the following spring. During the first warm days of spring this starch rapidly changes into sugar, which dissolves in the sap. This sugary sap exercises a very strong osmotic pressure. Water is therefore very rapidly absorbed in large quantities by the root-hairs. The great pressure of this sap in the cells of the roots causes it to pass into the xylem vessels and forces it up the stem. The force exerted is called *root pressure.* Thus the growing parts receive the supplies of food and water needed for rapid growth. Root pressure under even the most favourable circumstances will only suffice to force the sap to a height of about 20 or 30 feet. *It soon ceases to exist: indeed it does so just when transpiration is becoming most active, i.e.* during summer. It is *therefore* evident that *root pressure is not the cause of the flow of the transpiration current,* although it aids it. In any case, *it is never great enough to force water and salts to the tops of the highest trees.*

To show Root Pressure in a Growing Plant (e.g. *Geranium, Vine*) *during Spring*—(The experiment fails if attempted during summer, when transpiration is active.)—Take the potted plant and cut off the stem about 6 inches above the soil level. Attach to the cut end a narrow vertical glass tube by means of a short length of rubber tubing. Make the joints air-tight. Support the tube by a stick thrust into the soil. Pour water into the tube so that it rises just above the rubber tubing. Water the soil. Examine after twenty-four hours. The water rises in the tube, the rise being due to root pressure.

How the Plant uses Water and Salts

Both are used in making protoplasm. Water enters largely into the composition of the protoplasm. It also dissolves salts, sugar, and other food materials, and carries them to the tissues. We have already seen that it is used in sugar (and starch) making. *Nitrates are specially needed for protein formation.* In the leaves they react with glucose, and form soluble *amino-compounds.* These are carried by the sieve-tubes of the phloem to all parts of the plant, particularly to the actively growing tissues. Here the protoplasm of the cells builds them up into proteins, and finally into protoplasm. The necessary sulphur, phosphorus, and other elements are obtained from sulphates, phosphates, and other salts dissolved in the water of the transpiration current. The oxidation of glucose liberates the energy needed by the protoplasm for carrying out these reactions.

QUESTIONS

1. Describe and sketch the structure of a green leaf.
2. Why does a green plant need carbon dioxide? From what source is it obtained? Describe an experiment to show how it enters the plant.
3. Compare the effect on the air in which it lives of a green plant kept (*a*) in light, and (*b*) in darkness.
4. How does the green plant make use of (*a*) carbohydrates, (*b*) mineral salts?
5. Explain how water passes from the soil to the leaves of a green plant.

CHAPTER XXIV

RESPIRATION IN THE GREEN PLANT

Internal or "Tissue" Respiration—

As in the animal so also in the plant, internal respiration takes place at all times in all living cells. In this process glucose dissolved in the cell-sap is oxidised by oxygen dissolved in the sap. Carbon dioxide and water are formed, and energy is liberated. This energy enables the protoplasm of the plant cells to carry on its various activities.

External respiration is also a continuous process, but the plant shows no "breathing movements." Although the oxygen used in respiration is originally obtained from the air, we shall find that the plant does not always absorb it directly from the atmosphere.

How the Green Plant Respires in Darkness

In darkness the oxygen used by the plant is obtained *directly* from the atmosphere. Air diffuses through the stomata of the green plant into the intercellular spaces. Some of its oxygen dissolves in the film of water covering the walls of the cells bounding the spaces, passes into the cell-sap, and is used in the process of internal respiration. The carbon dioxide produced in the plant cells travels by the same path, but in the opposite direction, and so reaches the atmosphere.

Most non-green plants respire in this way at all times. A few very lowly non-green plants, *e.g.* some bacteria, can respire in the absence of air. The oxygen they need is supplied by decomposition of their protoplasm.

To show the Respiration of a Green Plant in Darkness—Tie a small test-tube to a piece of glass rod about 6 inches long so that the top of the test-tube is just below the top of the rod. Place a few cubic centimetres of water in the test-tube. Place the cut end of a leafy shoot in the water. Set the shoot, test-tube, and rod in a large flask inverted in a vessel of freshly made baryta water as shown in fig. 180.

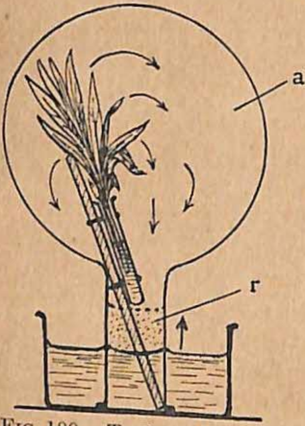


FIG. 180.—To show the respiration of a green plant (or of a leafy shoot) in darkness

a = air, into which the plant liberates carbon dioxide, r = baryta water, absorbs the gas, turns cloudy, and rises in neck of flask.

Set up a control, omitting the leafy shoot. Set both pieces of apparatus in darkness. Examine after twenty-four hours. In the flask containing the cut shoot the baryta water is very cloudy, and has risen in the flask. In the other flask the cloudiness is hardly noticeable, and there is no rise of the baryta. This shows that the leafy shoot has absorbed oxygen, and has given out carbon dioxide.

Repeat the experiment, keeping the apparatus in the light. The baryta does not rise, nor does it become cloudy. Plunge a lighted taper into the flask. The taper burns more brightly than before. This shows that in light the leafy shoot has not taken oxygen from the air. It has not given out carbon dioxide into the air, but has actually given out oxygen.

We know that the green shoot used in the last experiment (*i.e.* kept in a lighted situation) must respire. It is clear that it obtains its oxygen from another source than the atmosphere. This source is the oxygen produced by photosynthesis (see p. 213 and fig. 174).

How the Green Plant Respires in Light

You know that in light the green plant takes in carbon dioxide from the air, and gives out oxygen into it. *In light, respiration and photosynthesis both continue.* Photosynthesis results in the production of more oxygen than the green plant needs for respiration. Hence the plant takes in no oxygen from the air, but *supplies its needs from the oxygen produced within its cells by photosynthesis. The excess oxygen passes into the air.* On the other hand, carbon dioxide is taken in from the air. This is because the carbon dioxide produced in the cells by the process of respiration is less than the plant needs for photosynthesis.

To show the Respiration of Non-green Plant Tissues—Set up the apparatus used in the preceding experiment, but use a stalk of Celery, pieces of Mushroom, flower petals in a linen bag, or pieces of well-washed roots, instead of the leafy shoot.

The baryta rises and turns cloudy, whether the experiment be performed in darkness or in light. This shows that the non-green tissues take oxygen from the air, and give out carbon dioxide at all times.

To show the Respiration of Seeds—Take a glass U-tube and fit it up as in fig. 181. Fill it to a depth of about one inch with fresh baryta water. Support six or eight soaked peas about one inch above the level of the liquid. Stopper both limbs with rubber stoppers. Mark the level of liquid in each limb. Leave for twelve hours. The baryta rises in the limb containing the peas and turns cloudy. This shows that the peas have taken in oxygen, and have produced carbon dioxide, which has been absorbed by the baryta.

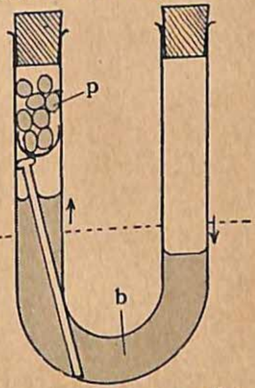


FIG. 181.—To show the respiration of seeds (peas) in air (aerobic respiration)

p = peas, b = baryta water, absorbs carbon dioxide produced by respiration of peas, and rises in limb of tube. If olive oil be used the gas is not absorbed, and there is no rise.

Dry dormant seeds, although resting, are alive, hence they respire. Because they are inactive they need little energy, and hence little oxygen. The little they need is supplied by the decomposition of their protoplasm. This enables them to live and respire in the absence of air. This respiration in the absence of air is *anaerobic respiration.*

Respiration in the presence of air is *aerobic respiration.* It produces much more energy, hence is the mode of respiration of all active living organisms. A few animal parasites which live within the tissues, or in the gut, of other animals carry on anaerobic respiration. They lead inactive lives, and are surrounded by ready-digested food which they can readily absorb. Hence they need little energy, and therefore little oxygen.

Lenticels—In woody plants the epidermis of the stem is replaced by a covering of impervious tissue—mainly dead corky tissue—called *bark.* In places this splits, forming small ventilation openings called *lenticels*. These communicate with intercellular spaces in the underlying ground tissue (cortex) of the stem, and perform the function of stomata. Lenticels are usually visible as small, rounded, slightly raised, oval or linear markings on the bark of woody stems.

To show the Presence of Lenticels in the Rind (Bark) of a Twig, and of Intercellular Spaces communicating with them—If a summer twig be used, all parts, including leaves, must be intact. If a winter twig, all buds must be intact.

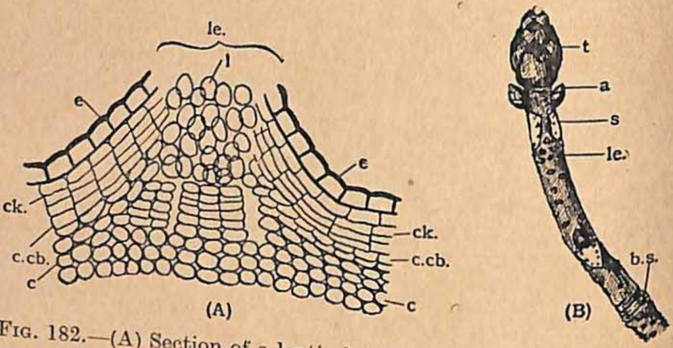


FIG. 182.—(A) Section of a lenticel (diagrammatic).
(B) Horse Chestnut (winter twig with lenticels)
l=loose cells, *le*=lenticel, *e*=epidermis, *ck*=cork, *ccb*=cork cambium (phellogen), c=cortex, *t*=terminal bud, *a*=axillary (lateral) bud, *s*=leaf scar, *bs*=bud scale scars of previous year's terminal bud. From *bs* to *t*=one year's growth of twig.

Take a cut twig (*e.g.* Horse Chestnut). To the cut end of the twig attach a length of rubber pressure tubing. Attach a foot-bellows to the other end of the tubing. Make joints air-tight. Immerse the whole twig—and leaves if a summer twig be used—in a large trough of water. Pump air into the twig. Air-bubbles emerge from the lenticels, and burst—also from stomata of leaves of summer twig. This shows the presence of lenticels (and stomata), and that there is a system of air spaces within the twig communicating with them.

QUESTIONS

1. Describe the respiration of a green plant in darkness. Give an experiment to illustrate this process.
2. Explain the process of respiration in a green plant kept in a well-lighted place.
3. Explain how (*a*) resting, (*b*) germinating, seeds respire. How could you demonstrate the respiration of seeds?
4. Describe and sketch a lenticel. What is its function?

CHAPTER XXV

THE SEED: ITS STRUCTURE AND GERMINATION. THE SEEDLING

How a Seed is Formed, and How it becomes a Seedling

A seed consists of a very small, immature plant (*plant-embryo*) and a store of food, enclosed within a seed-coat (*testa*). Seeds are produced only by flowering plants. It has already been stated (Part II, p. 127) that after the egg-cell (*ovum*) within an ovule has been fertilised, the ovum develops into a multicellular *embryo*. The ovule grows, and becomes the *seed*. The hardened ovule-wall becomes the *testa*. Meanwhile the parent plant supplies even more food than is immediately needed by the developing seed. This dissolved food is carried to the seed by the tubes of the vascular bundles of the parent plant (Part II, p. 126). In some seeds the " spare " food is stored within the embryo, which enlarges to fill the whole seed. In others, the food is stored in a mass of cells, which fills the space between the embryo and the testa. The growth of the seed soon ceases, and the ripe seed is shed. It then passes through a resting (*dormant*) period. At the end of this period—*but only if conditions be favourable*—the seed germinates. The embryo absorbs the remainder of the stored food, develops, and grows into a young independent plant. This is the *seedling*.

THE BROAD BEAN SEED

Examine Bean seeds as obtained from the seedsman

They are in a dormant condition. The kindey-shaped seed is hard and dry. Its testa is leathery and wrinkled. At its thick end is a long, narrow, grey-black scar. This is the *hilum*, at which the seed was attached to the fruit (pod). Near, and pointing towards the hilum, is a low wedge-shaped projection.

This shows the position of the young root (*radicle*) of the embryo lying beneath the testa.

Soak some of the seeds in water for about twenty-four hours

Their contents swell and soften. *Squeeze a soaked seed.* A drop of water oozes from a small hole in the testa between the radicle and the hilum. This hole is the *micropyle* (Gk. *mikra* = small, *pule* = gate). *Remove the testa.* The cream-coloured embryo fills the whole of the space enclosed by the testa. Most of the embryo consists of a pair of large, oval, fleshy seed-leaves or *cotyledons* (Gk. *kotuledones* = suckers). *Pull the cotyledons apart.* They are united at one point of their concave border. Their outer surfaces are convex, their opposed faces are flat. From the joined part of the two cotyledons the conical radicle extends along their edges towards the thick end of the embryo. *Break away one cotyledon.* The young shoot (*plumule*) is seen. It is continuous with the radicle, but points in the opposite direction.

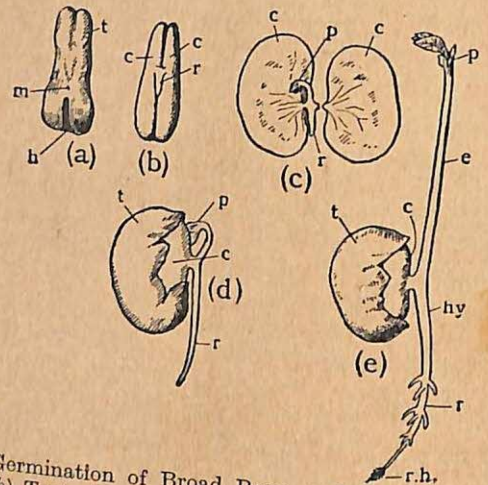


FIG. 183.—Germination of Broad Bean seed. (*a*) External appearance; (*b*) Testa (seed coat) removed; (c) Cotyledons separated; (*d*) early stage of germination; (*e*) older seedling

t = testa, *m* = micropyle, *h* = hilum, *c* = cotyledon, *r* = radicle, *p* = plumule, *e* = epicotyl (stem above cotyledons), *hy* = hypocotyl (stem below cotyledons), *rh* = root-hairs. (The cotyledons are hypogeal.)

It lies between the cotyledons, and its tip curves towards the centre of the seed. It consists of a short stem bearing a pair of small, folded leaves with a tiny bud between them. Each cotyledon is joined to the base of the plumule by a very short leaf-stalk (*petiole*).

The cotyledons contain enough food to supply the needs of the embryo until it becomes a seedling with roots and green leaves, and is then able to feed itself. The dissolved food brought to the cotyledons is changed to insoluble forms for storage until needed.

To show the Nature of the Food stored in the Cotyledons—Take two test-tubes. Place a small piece of cotyledon in each. To one add a few drops of iodine solution. The cotyledon turns blue-black. This shows that it contains starch. To the second add a few drops of strong nitric acid. Heat. It turns yellow. Cool. Add a little strong ammonium hydrate. Warm. It turns orange. This shows that it contains protein.

The Resting (Dormant) State of the Seed

This may be only a few days, or may last for several months, *e.g.* from autumn until the next spring. Some dry resting seeds have been kept alive for nearly one hundred years. *The dormant seed needs little food and oxygen. These it obtains from its stored food.* It has already been explained on p. 225 that dormant seeds respire in the absence of atmospheric oxygen, hence the oxygen used must have been obtained from the food in the seed (*anaerobic respiration*). The dormant seed can resist considerable drought, and extremes of heat and cold. This power is of great value, as it enables the seed to tide over very unfavourable periods, and so saves the species of flowering plants from extinction.

Conditions Necessary for the Germination of Seeds

Even after it has completed its normal resting period the seed will not germinate except under favourable conditions. These include:

(a) *Presence of Water*—Just before germination the seed absorbs much water. Its cells become turgid. The testa softens and becomes very permeable, and air enters the seed.

(b) *An Abundant Supply of Air*—The seed needs oxygen to oxidise some of its stored food, in which process energy is liberated. This energy is needed for the activities which make up the process of germination. The oxidation of food with the liberation of energy is the process of *internal respiration.* It is rapid, and the seed absorbs much oxygen, and gives out much carbon dioxide and water vapour. This is *external respiration.* The experiment described on p. 225 showed that seeds respire in the presence of air (*aerobic respiration*). That they will not germinate in the absence of air will presently be shown.

(c) *A Suitable Temperature*—For each plant there is a temperature below which its seeds will not germinate. Every rise of temperature beyond this hastens the rate of germination, until a temperature is reached above which the seeds will not germinate. This high temperature kills their protoplasm. These limits of temperature differ for different species of flowering plants. This is the reason why some plants are found only in cold, and others only in hot climates.

To find if Water and Air are needed for the Germination of Seeds—Take three shallow dishes containing respectively (*a*) dry sawdust, (*b*) damp sawdust, (*c*) freshly boiled water cooled to air temperature. Place a few Bean seeds in each. Cover the surface of the water with a film of olive oil to exclude air. Leave the dishes in a warm place. *Examine daily.* Only the seeds in (*b*) germinate. These only have received both air and water. Those in (*a*) received air but no water; those in (*c*) received water but no air.

To find the Effect of Temperature upon the Rate of Germination of Seeds—Place seeds (*e.g.* Barley, Peas, or Beans) in two beakers containing damp sawdust. Place one beaker in a warm place, the other in the coldest place available. If possible, stand this beaker in a larger vessel containing ice. *Examine daily. Note the progress of germination.* It is much more rapid in the case of seeds in the warmed beaker.

These experiments enable us to understand why warm weather and loose damp soil favour germination, whereas cold weather and a close dry soil, or a water-logged soil, are unfavourable.

Chemical Changes taking place within the Seed at Germination

The stored food in the seed is insoluble and consists of starch, or oil, and proteins. These substances must be carried *in solution* to the growing cells of the embryo. They are dissolved, or *digested* by *enzymes* similar to those found in the alimentary canal of an animal (p. 163). *Starch* is changed into *sugar* by *diastase*, an enzyme similar to the ptyalin found in saliva. The sugar travels in solution to the growing parts of the embryo. Here it is oxidised, carbon dioxide and water are formed, and energy set free. *Oils* also are changed into simpler bodies, including *sugar*, which is similarly used. *Proteins* are acted upon by other enzymes, and changed into *amino-compounds*. These travel in solution to the cells of the growing parts of the embryo. The energy set free from the oxidised sugar enables the protoplasm of the cells to build up more protoplasm from the amino-compounds. These reactions taking place in the germinating seeds are accompanied by the evolution of heat.

To show that Germinating Seeds evolve Heat—Take a beaker containing a large number of Barley grains or Peas germinating in damp sawdust. Place a thermometer among the seeds. Note the temperature recorded. Compare with air temperature. The temperature of the germinating seeds is higher.

Allow Bean seeds to germinate in damp sawdust. Examine at intervals. Note the stages of germination. Make careful sketches.

The radicle lengthens, and bursts through the testa near the micropyle. It does not emerge through the micropyle. It grows downwards, and develops *root-hairs* just behind the region of most rapid elongation (see *Geotropism*, Part II, pp. 156–158). The *plumule* lengthens, especially at some distance behind its tip, which remains between the *cotyledons*. The lengthening stem of the plumule arches, and then bursts through the testa. The arch of the stem rises above the surface of the sawdust. The stem straightens. The tip of the plumule and the young leaves are drawn out from between the cotyledons. The cotyledons remain within the split testa. They gradually shrivel as the food they contain is used in feeding the lengthening radicle and plumule. The lengthening stem raises the young leaves above the sawdust. They turn green, unfold, and grow, becoming the first foliage leaves of the young seedling. The root-hairs absorb water and dissolved salts from the damp sawdust, which should be watered with soil-water from time to time. The green leaves respire, transpire, and make food.

Lateral roots develop on the main root above the zone of root-hairs. By this time most of the food in the cotyledons has been absorbed by the seedling, which is now established as an independent young plant.

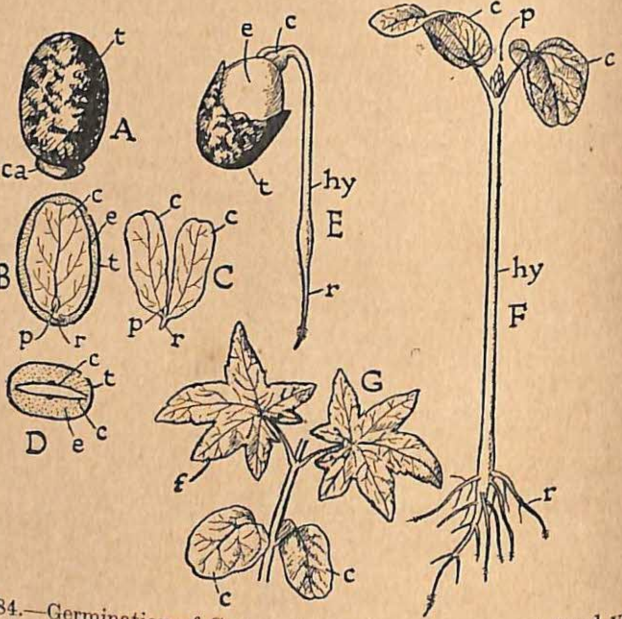


FIG. 184.—Germination of Castor-oil seed. (A) Seed; (B) Seed vertically bisected; (C) Embryo; (D) Seed horizontally bisected; (E) Young seedling; (F) Older seedling; (G) Cotyledons and pair of foliage leaves

t=testa, *ca*=caruncle, *e*=endosperm, *c*=cotyledons, *p*=plumule, *r*=radicle (roots in F), *h*=hypocotyl, *f*=foliage leaf. (The cotyledons are epigeal.)

THE CASTOR-OIL SEED

Examine the Seed

The seed is oval and somewhat flattened from side to side. The testa has a peculiar mottled and streaked appearance. At one end the seed bears a large oval spongy outgrowth. *This is the caruncle.* The micropyle is just above it.

Remove the testa of a soaked seed

A large white mass is uncovered. There is no sign of radicle or plumule.

Bisect one seed vertically and parallel with its wider surface. Bisect another horizontally.

It is found that the embryo consists of a pair of thin, flat, oval cotyledons with a small conical radicle projecting down from their base, and a small spindle-shaped plumule lying between them. This small embryo is embedded in a white mass which is uncovered when the testa is removed. It is a mass of tissue containing stored food, and is called *endosperm* (Gk. *endo* = within, *sperma* = seed).

To find the Nature of the Food stored in the Endosperm of the Castor-oil Seed—Test for starch as in the case of the Bean seed. None is found. To a piece of endosperm in a test-tube add a few drops of one per cent. osmic acid. It turns black. This shows the presence of a fat or oil. Rub a piece of endosperm on a piece of white paper. It makes an oily stain. Oil takes the place of starch as energy-producing food in this seed. Test for protein as in the case of the Bean seed. Protein is present. *Allow soaked seeds to germinate in damp sawdust. Note the stages of germination. Sketch.*

As the embryo absorbs food from the softening endosperm, the part of the embryo between the cotyledons and the radicle elongates. The radicle bursts through the testa and grows downwards. The stem between the radicle and the cotyledons lengthens and arches upwards. It is called the *hypocotyl* (Gk. *hypo* = below). The hypocotyl lengthens and straightens. The cotyledons still embedded in the remains of the endosperm, and enclosed by the split testa, are dragged above the surface of the sawdust. The cotyledons turn green. By this time practically all the endosperm has been absorbed by them. The testa, and any endosperm that may remain, now fall off. The green cotyledons enlarge, and become the first pair of green leaves of the seedling. Meanwhile the plumule develops, and the first pair of true foliage leaves appear and grow. *Notice that their shape is different from that of the simple oval cotyledons.* The food needed for their development has been made by the cotyledons, which respire, transpire, and carry on photosynthesis.

By this time root-hairs and lateral roots have developed, and water and salts are absorbed, carried to the cotyledons, and are used in food-making.

The Bean Seed and Castor-oil Seed compared

Two cotyledons are present in each embryo. Hence the Bean and the Castor-oil are both termed DICOTYLEDONS. There is no endosperm in the Bean seed. It is therefore termed a *Non-endospermic* seed. The Castor-oil seed is *Endospermic*. The cotyledons of the Bean embryo remained underground. They are therefore termed *Hypogeal* cotyledons (Gk. *hypo*= below, *ge*=earth). The cotyledons of the Castor-oil embryo came above the ground, turned green, and acted like foliage leaves. They are therefore *Epigeal* (*epi*=above).

THE MAIZE GRAIN

This is really the fruit, and encloses the seed.

It is yellow, hard, and wedge-shaped. At the middle of one edge of the broad end of the grain there is a very small conical tuft. This is the remains of the *stigma* (Part II, p. 127). Its presence shows that the grain is a fruit formed from the ovary (Part II, p. 127). The narrow end of the grain bears the remains of a short stalk which united the fruit to the "cob." On one broad face of the grain is an oval white area. This shows the position of the *embryo*.

Soak a grain for twenty-four hours. Remove the thin skin.

This is the fruit wall or *pericarp* (Gk. *peri*=around, *karpos* =fruit), with the testa united with it. They are removed together. Note that a vertical furrow bisects the embryo-area.

Tease the white tissues outwards along the edges of the furrow.

This tissue is the infolded edges of the single cotyledon, and covers the *radicle* and *plumule*. These are now uncovered. The radicle is conical, the plumule is spindle-shaped. At their junction they are united to the centre of the cotyledon. The cotyledon is shield-shaped, and is therefore called the *scutellum* (Lat., little shield). This shield-shaped cotyledon is common to all "grasses." The flat part of the scutellum lies against a mass of endosperm, which fills the remainder of the seed. The part of the endosperm next to the scutellum is white and starchy. The remainder is yellow, and contains sugar.

Bisect one soaked grain vertically at right angles to a broad face. Bisect another grain horizontally. Examine and make out the arrangement of the parts of the embryo.

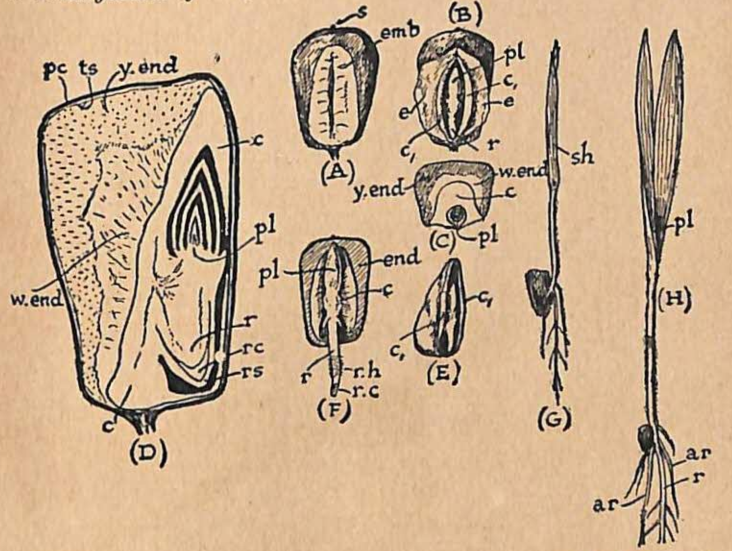


FIG. 185.—Structure and germination of Maize 'seed' (Maize grain). (A) Side view of grain; (B) Grain with pericarp (envelope) and edges of cotyledon (scutellum) turned back to expose embryo; (C) Horizontal, (D) Vertical, section of grain; (E) Embryo removed from grain; (F) Germinating grain; (G) and (H) Maize seedlings

ar = adventitious roots, *pc* = pericarp, *c* = cotyledon (scutellum), c_1 = turned back edges of cotyledon, *e* = turned back edges of envelope (pericarp), *emb* = embryo, *pl* = plumule, *r* = radicle, *rc* = root-cap, *rs* = root-sheath, *s* = vestige of stigma, *ts* = testa, *w.end* = white (starchy) endosperm, *y.end* = yellow (sugary) endosperm, *rh* = root-hairs, *sh* = sheath, *end* = endosperm.

The plumule and the radicle are each enclosed in a hard sheath. They are overlapped on both sides, above, and below by the edges of the scutellum.

Allow soaked grains to germinate in damp sawdust. Note the stages of germination. Sketch.

The radicle lengthens. The hard root-sheath bursts its way through the skin of the grain. The radicle grows downwards and develops root-hairs. The plumule and sheath lengthen. The hard tip of the sheath bursts upwards through the skin of the grain, and rises above the sawdust. The sheath splits. The plumule turns green, and grows upwards above the sheath, which still encloses its base. The outer leaves unroll. Meanwhile the food in the endosperm has gradually been absorbed by the scutellum, and passed to the growing parts of the embryo. *Secondary* (*adventitious*) *roots* grow from the junction of the plumule and the radicle, and become as long as the radicle itself. The root-hairs absorb water and salts. The green leaves respire, transpire, and make food. The seedling is now an independent plant.

Since the Maize seed has only one cotyledon the plant is called a MONOCOTYLEDON and the seed is *Endospermic*.

Examine and germinate Wheat grains

Their structure and germination resemble those of the Maize. The endosperm, however, is mainly starchy, with an outer layer very rich in proteins.

Examine and germinate Onion seeds

The single cotyledon is hollow and conical, its base enclosing the plumule. In germination the tip of the cotyledon remains embedded in the endosperm, from which it absorbs dissolved food. The plumule bursts through and grows up from the side of the base of the cotyledon. This form of cotyledon differs from that of the "grasses," and is usual among Monocotyledons.

Seeds used by Man

Man grows many crops for the sake of the seeds. Some kinds of seeds he uses as food. Others are used in various industries. Leguminous plants (pod-bearing plants), *e.g.* Bean, Pea, have seeds very rich in starch and proteins. These are valuable foods. Cereals (grasses), *e.g.* Maize, Wheat, Barley, Rice, have starchy seeds with smaller proportion of protein. These also are valuable foods. Useful oils are extracted from some seeds. Such are cotton-seed oil from seeds of the Cotton plant, castor-oil from seeds of the Castor-oil plant, palm-oil from seeds of the Palm tree, linseed-oil from the Flax seed. Coffee is obtained from the seeds of the Coffea, cocoa from those of Cacao. In both of these cases the seeds are roasted and ground.

QUESTIONS

1. Describe and sketch the seed of the Broad Bean.
2. What food-stuffs are stored in seeds? Where are they found in the seed? What is the use of each, and how would you prove its presence?
3. Describe the structure and germination of the Castor-oil seed.
4. What conditions are necessary for the germination of seeds?
5. What changes take place in the seed at germination?
6. Describe the structure and germination of the seed of the Maize. How does the Maize grain differ from the seeds described in this chapter?

ANSWERS TO NUMERICAL EXAMPLES

CHAPTER VII, p. 51.

4. (i) 6 cm. real; 1 cm. high, inverted.
(ii) 12 cm. real; 4 cm. high, inverted.
(iii) 4 cm. virtual; 4 cm. high, erect.

5. (i) 3 cm. virtual; 0·5 cm. high, erect.
(ii) 2·4 cm. virtual; 0·83 cm. high, erect.
(iii) 1·33 cm. virtual; 1·5 cm. high, erect.

6. (i) 6 cm. real; 1 cm. high, inverted.
(ii) 12 cm. real; 4 cm. high, inverted.
(iii) 4 cm. virtual; 4 cm. high, erect.

7. (i) 3 cm. virtual; 0·5 cm. high, erect.
(ii) 2·4 cm. virtual; 0·83 cm. high, erect.
(iii) 1·33 cm. virtual; 1·5 cm. high, erect.

9. (*a*) 7·5 cm.; (*b*) 5·0 cm.

10. (*a*) 16 cm.; (*b*) 8 cm.

CHAPTER XII, p. 96.

3. 276·9 c.c.

4. 133·7 c.c.

5. 8·90.

CHAPTER XIII, p. 116.

3. 322 grams.

4. 9 tons.

5. 1·86 litres.

6. 25 grams.

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